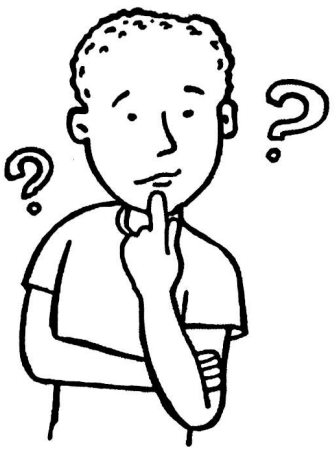
مراجعة ال
الكترونيات
أولى كهرباء

Electronics_1

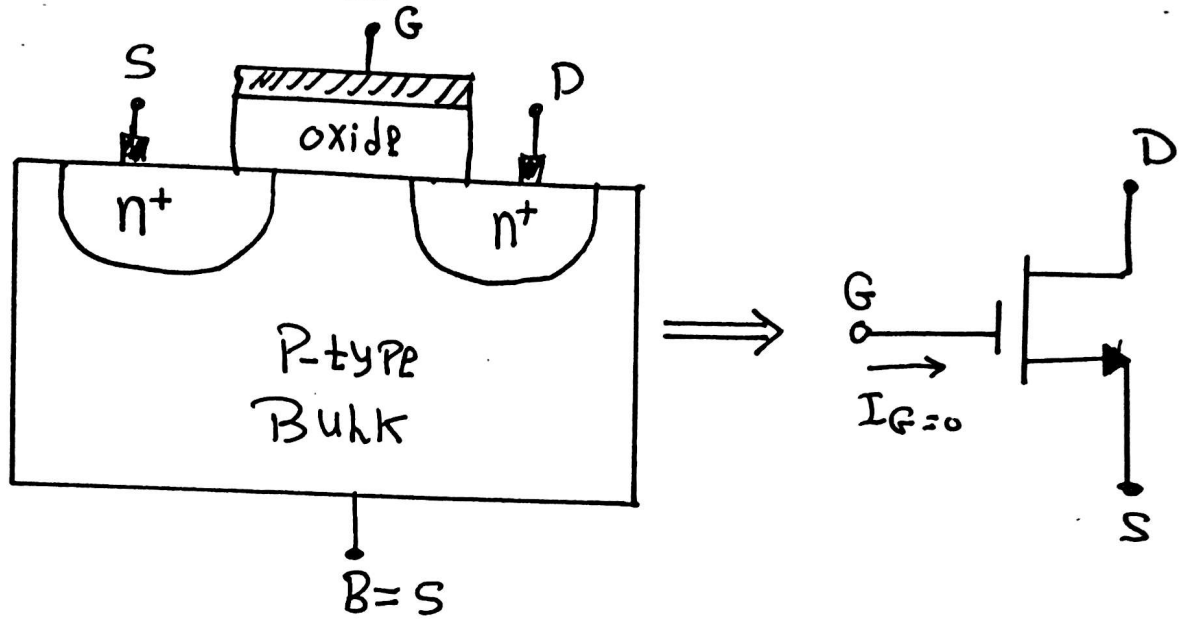


Final Revision

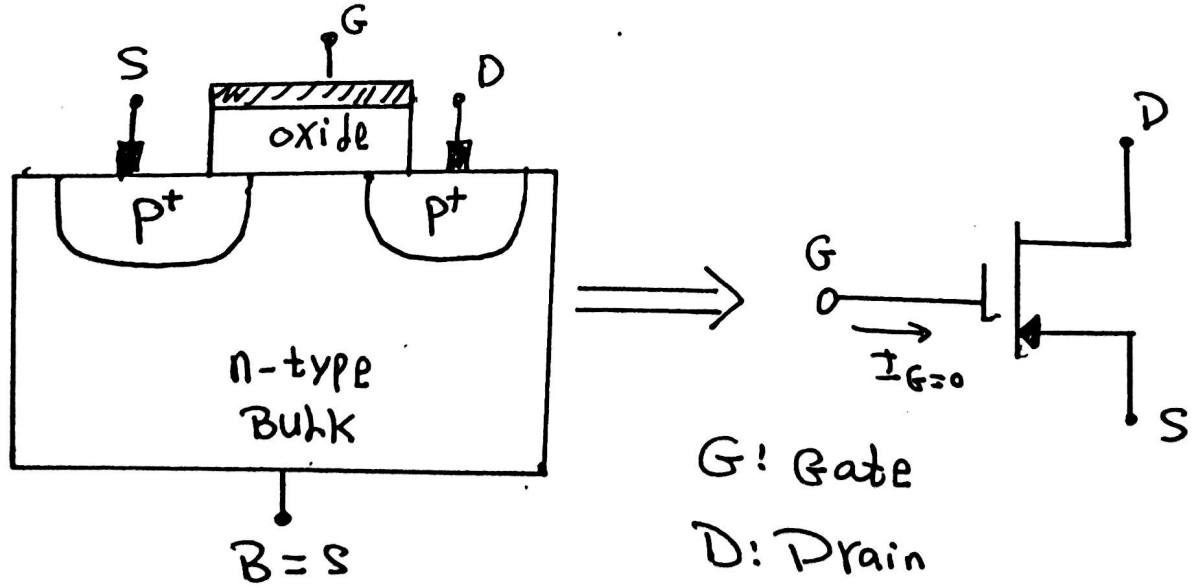
Part (1)

MOSFET

N-MOSFET:



P-MOSFET :



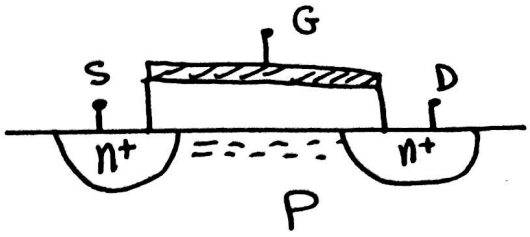
G: Gate

D: Drain

S: Source

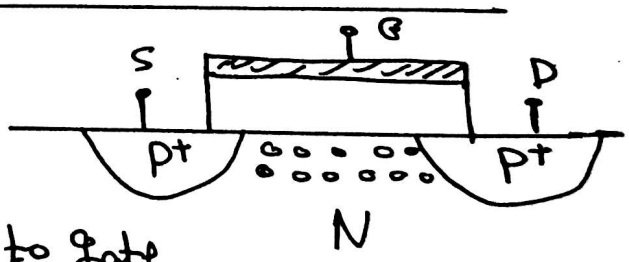
B: bulk

Explain the channel formation in N Mosfet?



* V_{GS} = +ve : Electric field moves from gate to substrate
* This electric field force electrons to move opposite to its direction. and electrons accumelated near gate.
* As a result, inverted Layer is formed between saurce & drain (Note: Normally off)

Explain the chamel formation of p Mosfet?

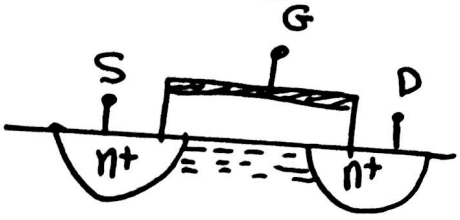


* V_{GS} = -ve : Electric field moves from substrate to gate
* this electric field force holes to move in its direction and holes accumelated near gate
* As a result, inverted Layer is formed between saurce & drain (Note: Normally off)

Explain different operating regions of NMOS:

$V_{GS} \leq V_t \longrightarrow$ Channel not formed and mosfet off

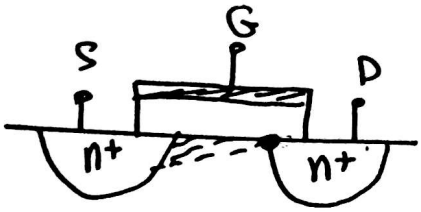
$V_{GS} > V_t$ $\quad (V_t = +Ve)$



$V_{DS} < V_{GS} - V_t$

Triode

Application: Variable resistance

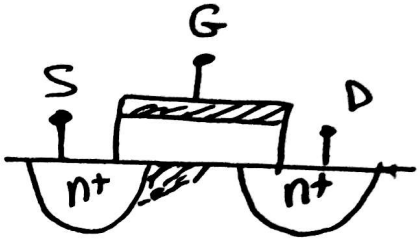


$V_{DS} = V_{GS} - V_t$

Edge between Triode & saturation

Pinch off at drain

Amplifier



$V_{DS} > V_{GS} - V_t$

Saturation

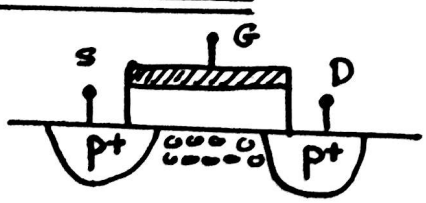
Amplifier

Explain different operating regions of PMOS:

$V_{GS} \geq V_t \longrightarrow$ Mosfet off because the channel is not formed

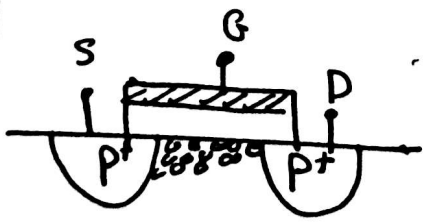
$V_t = (-Ve)$

$V_{GS} < V_t$



$V_{DS} > V_{GS} - V_t$

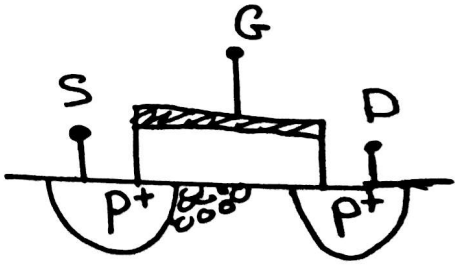
Triode



$V_{DS} = V_{GS} - V_t$

Pinch-off

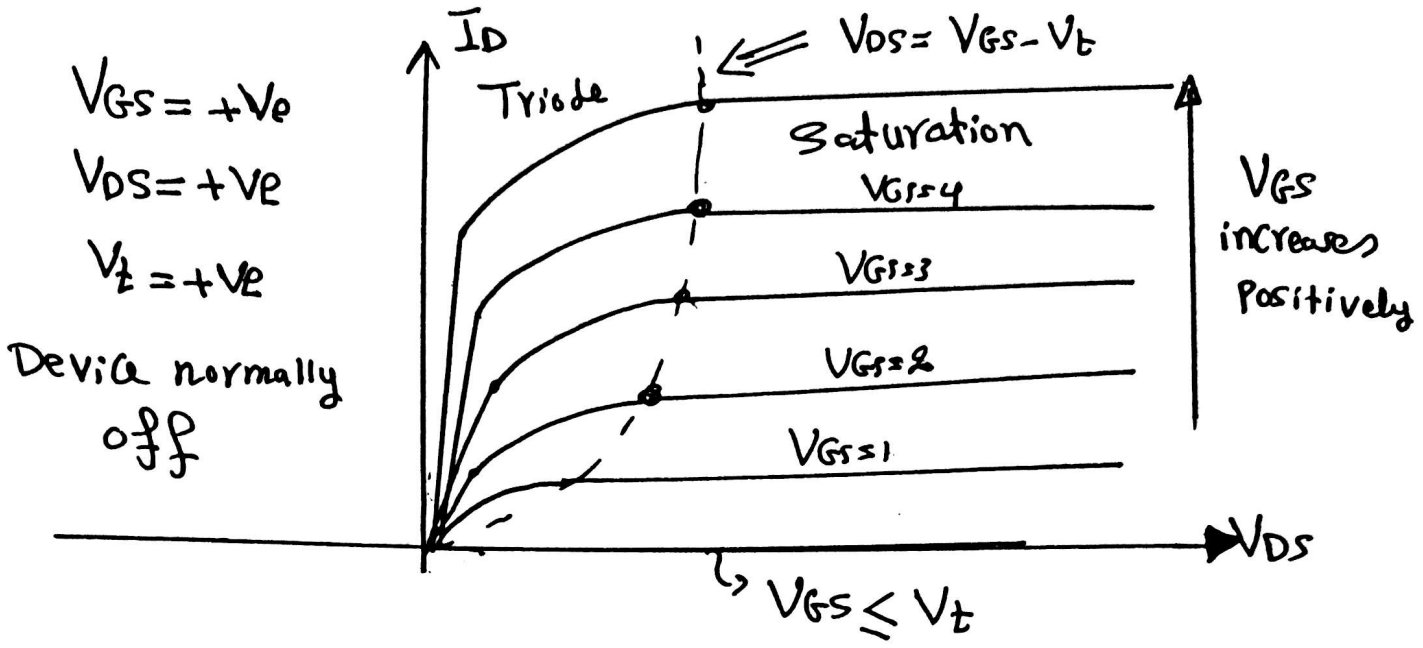
Edge between saturation & Triode



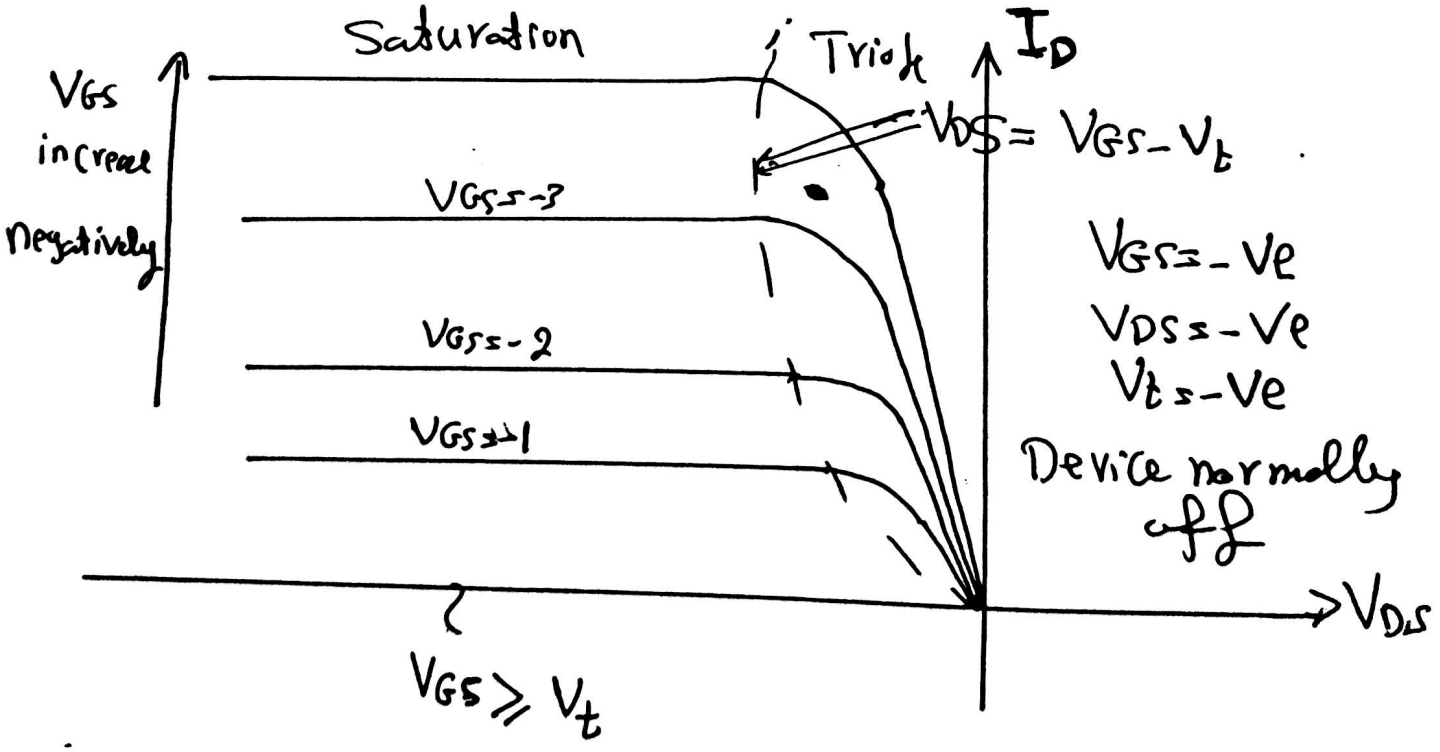
$V_{DS} < V_{GS} - V_t$

Saturation

Draw I_D / V_{DS} c/c's of n-channel Mosfet!



Draw I_D / V_{DS} c/c's of P-channel Mosfet!



What is the application of mosfet in Triode and Saturation regions.

Triode :

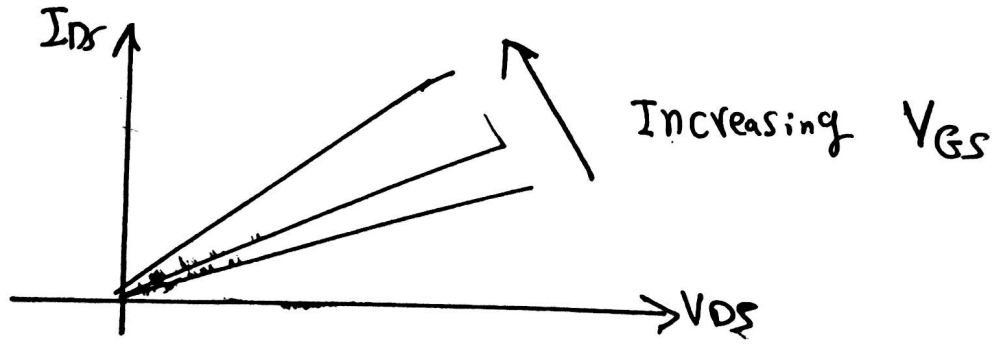
$$I_D = \frac{k_n}{2}\left[2(V_{GS}-V_t)V_{DS} - V_{DS}^2\right]$$

If V_{DS} is small $\Rightarrow$ we can neglect V_{DS}^2

$$I_D = k_n (V_{GS}-V_t) V_{DS}$$

$$R_{ds} = \frac{V_{DS}}{I_D} = \frac{1}{k_n (V_{GS}-V_t)}$$

$\rightarrow$ Voltage controlled resistance



Saturation Region:

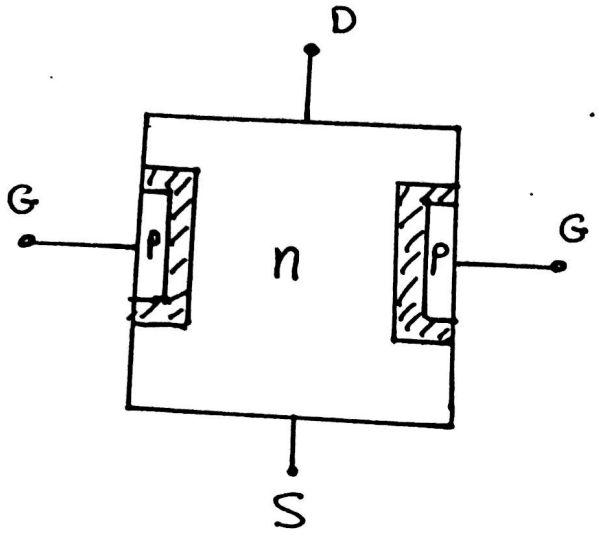
$$I_D = \frac{k_n}{2}(V_{GS}-V_t)$$

I_D : o/p

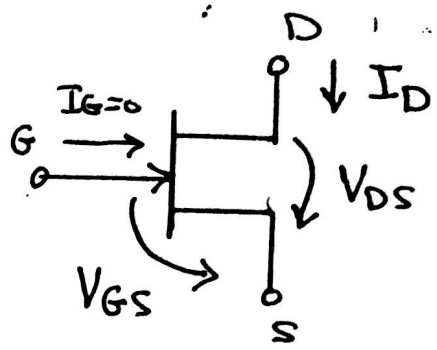
V_{GS} : I/p

Mosfet used as a transconductance Amplifier.

* JFET structure and circuit symbol:

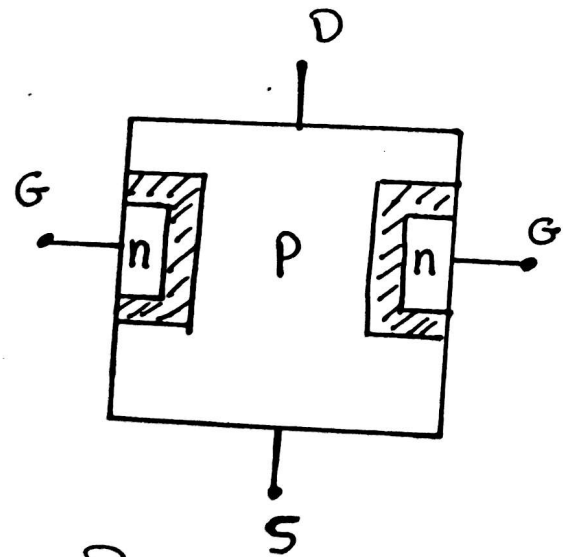


N-channel JFET structure

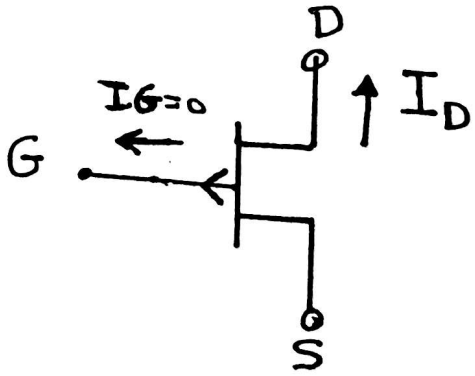


N-channel JFET symbol

G : Gate , S : Source , D : Drain



P-channel JFET structure



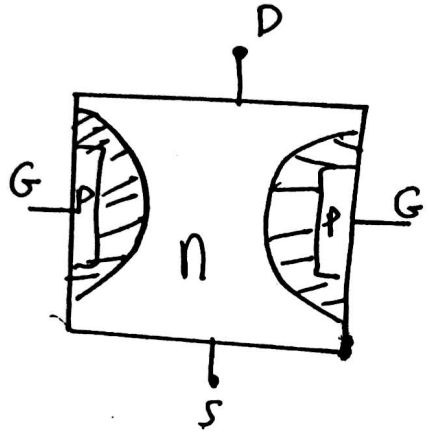
P-channel JFET symbol

Note : No current will pass through gate.

Explain different operating regions of n-JFET :

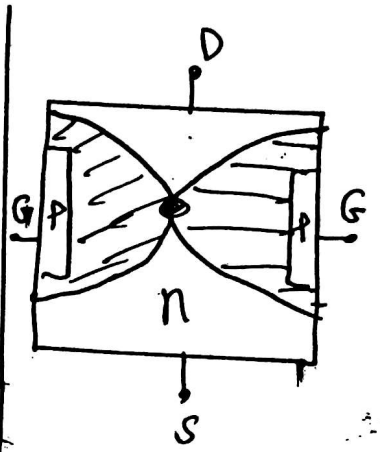
$V_{GS} \leq V_P \longrightarrow$ JFET off $(V_P = -Ve)$

$V_{GS} > V_P$ (normally ON) $\Rightarrow$ (max I_D at $V_{GS}=0$)



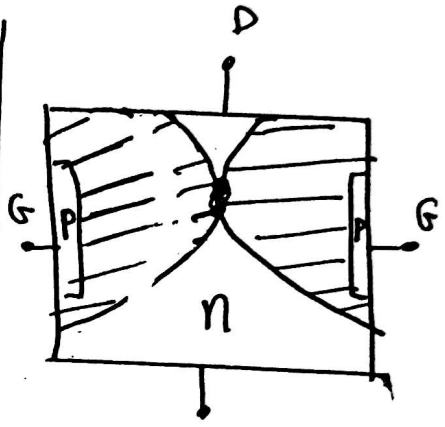
$V_{DS} < V_{GS} - V_P$

Triode



$V_{DS} = V_{GS} - V_P$

Edge



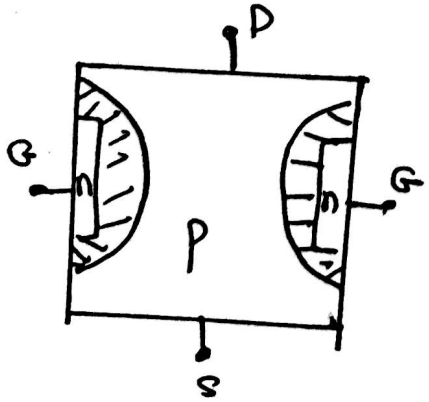
$V_{DS} > V_{GS} - V_P$

Saturation

Explain different operating regions of P-JFET

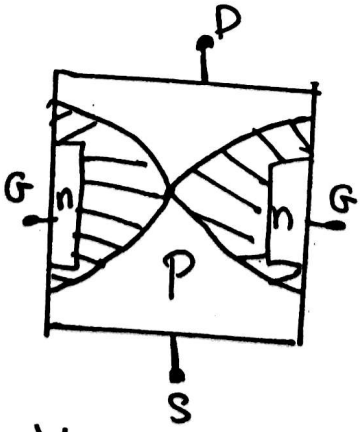
$V_{GS} \geq V_P \longrightarrow$ JFET off $(V_P = +Ve)$

$V_{GS} < V_P$ (normally ON) $\Rightarrow$ (max I_D at $V_{GS}=0$)



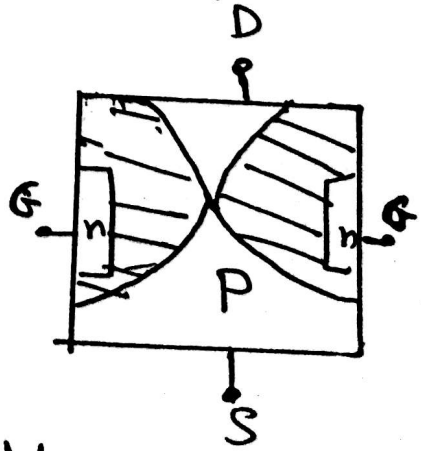
$V_{DS} > V_{GS} - V_P$

Triode



$V_{DS} = V_{GS} - V_P$

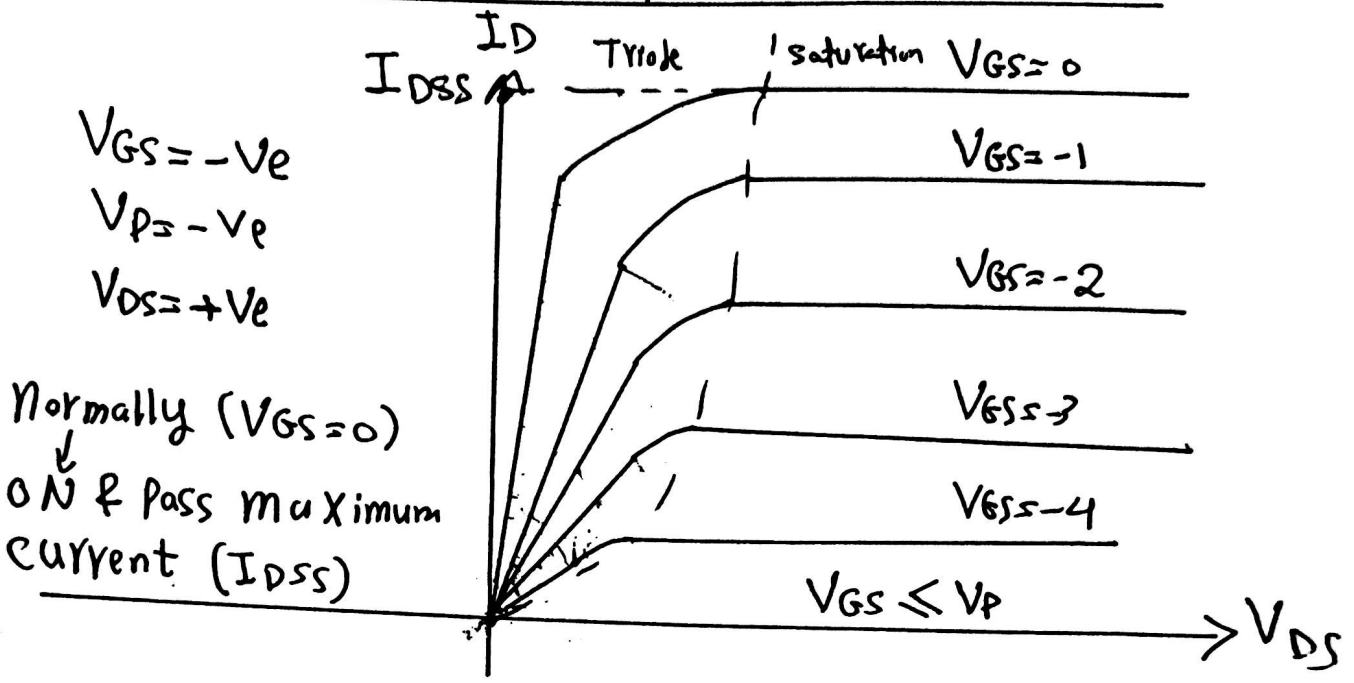
Edge



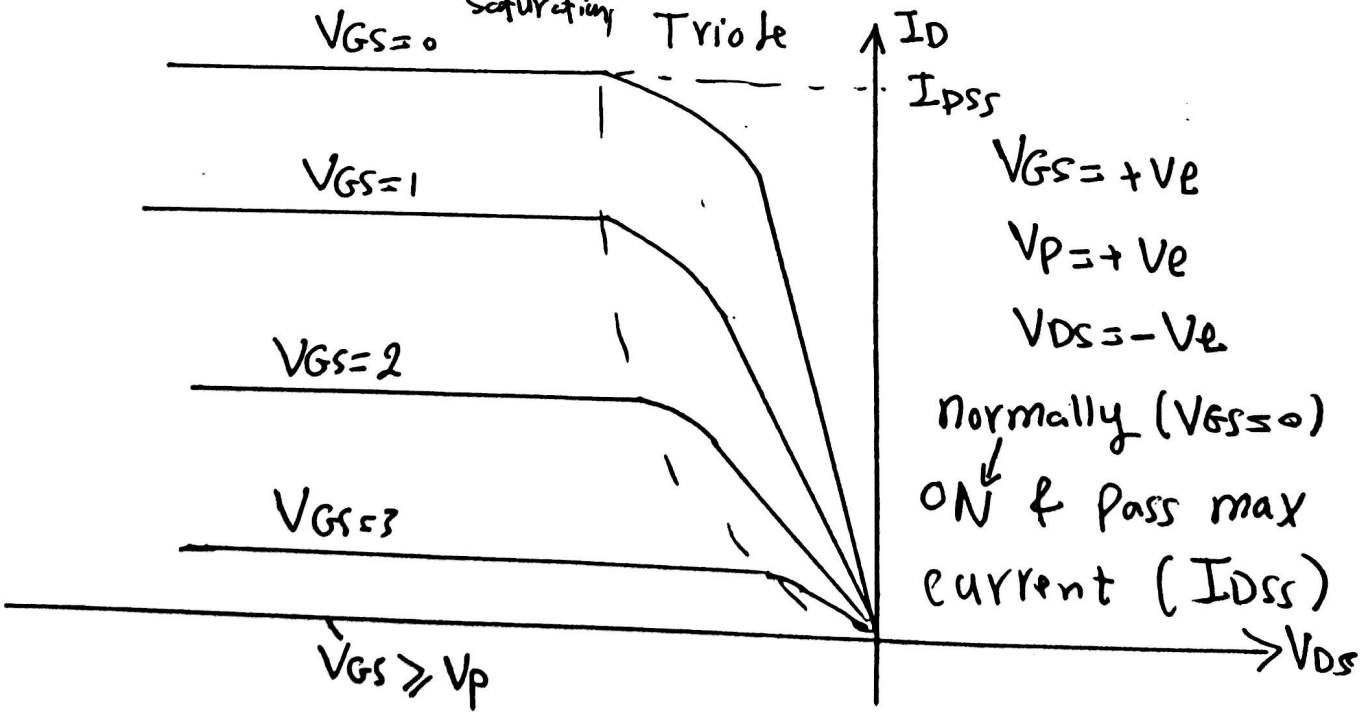
$V_{DS} < V_{GS} - V_P$

Saturation

* Draw I_D / V_{DS} C/C's of n-channel JFET:



* Draw I_D / V_{DS} C/C's of p-channel JFET:



*What is the application of JFET in Triode and Saturation regions?

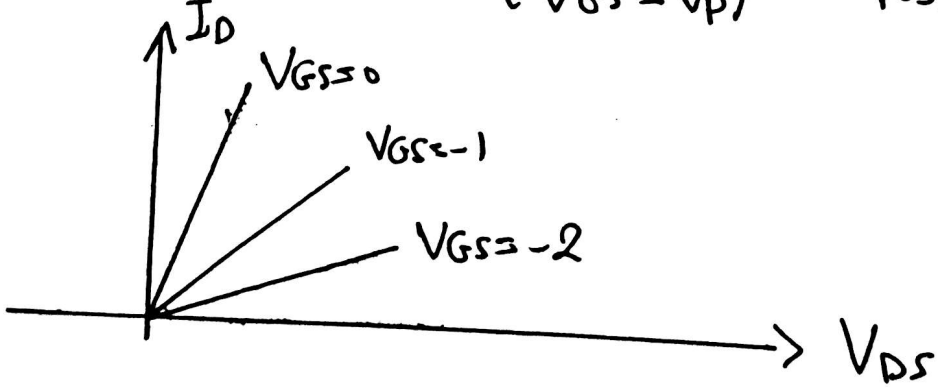
Triode

$$I_D = \frac{I_{DSS}}{V_P^2}\left[2(V_{GS}-V_P)V_{DS} - V_{DS}^2\right]$$

If V_{DS} small ⟶ neglect V_{DS}^2

$$I_D \simeq \frac{2I_{DSS}}{V_P^2}(V_{GS}-V_P)V_{DS}$$

$$R_{ds} = \frac{V_{DS}}{I_D} = \frac{V_P^2}{2I_{DSS}(V_{GS}-V_P)}$$ (Voltage Controlled Resistance)



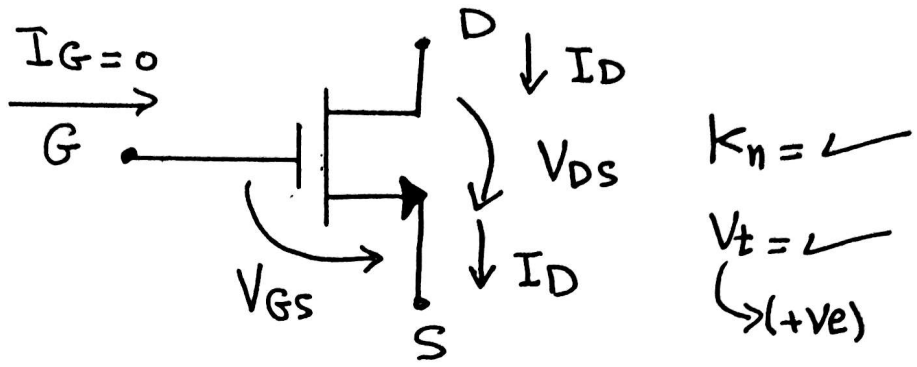
Saturation

$$I_D = \frac{I_{DSS}}{V_P^2}(V_{GS}-V_P)^2$$

I_D: o/p, V_{GS}: i/p

JFET used as a transconductance amplifier.

* N channel MOSFET DC analysis:



If $V_{GS} \leq V_t \longrightarrow$ MOSFET off $\longrightarrow I_D = 0$

If $V_{GS} > V_t$:

* Assume saturation :

$$\longrightarrow I_D = \frac{K_n}{2}(V_{GS} - V_t)^2$$

Check $\longrightarrow V_{DS} \geq V_{GS} - V_t$, Note $V_{GS} - V_t = V_{ov}$ (over drive voltage)

or $\longrightarrow V_{GD} \leq V_t$

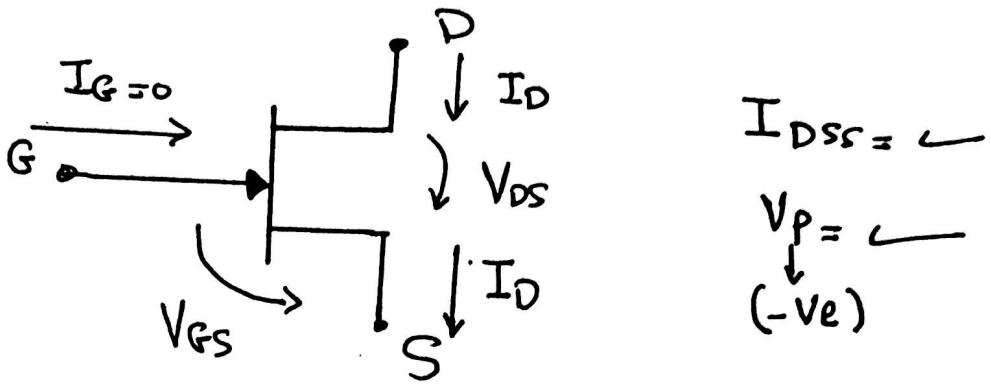
* If $V_{DS} < V_{GS} - V_t$ or $V_{GD} > V_t \Rightarrow$ assume Triode

$$\longrightarrow I_D = \frac{K_n}{2}\left[2(V_{GS} - V_t)V_{DS} - V_{DS}^2\right]$$

Check $\longrightarrow V_{DS} < V_{GS} - V_t$

or $\longrightarrow V_{GD} > V_t$

* N Channel JFET DC analysis:



If $V_{GS} \leq V_P \longrightarrow$ JFET off $\longrightarrow I_D = 0$

If $V_{GS} > V_P$:

* Assume saturation:

$$\longrightarrow I_D = \frac{I_{DSS}}{V_P^2}(V_{GS} - V_P)^2$$

Check $\longrightarrow V_{DS} \geq V_{GS} - V_P$

or $\longrightarrow V_{GD} \leq V_P$

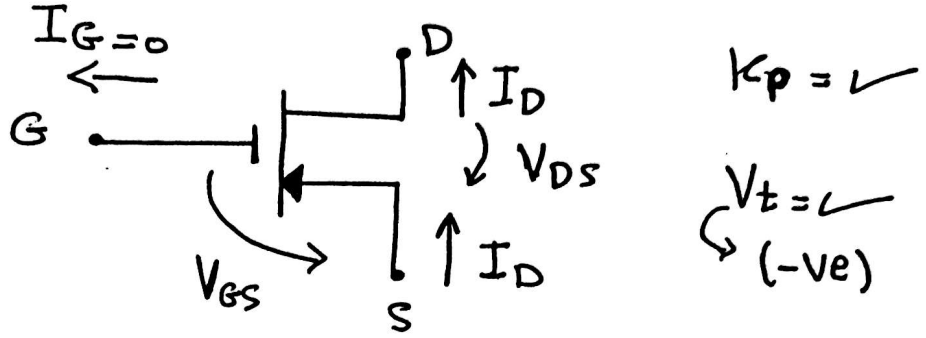
* If $V_{DS} < V_{GS} - V_P$ or $V_{GD} > V_P \Rightarrow$ assume Triode:

$$\longrightarrow I_D = \frac{I_{DSS}}{V_P^2}\left[2(V_{GS} - V_P)V_{DS} - V_{DS}^2\right]$$

Check $\longrightarrow V_{DS} < V_{GS} - V_P$

or $\longrightarrow V_{GD} > V_P$

* P Channel MOSFET DC analysis:



* If $V_{GS} \geq V_t \longrightarrow$ MOSFET off $\longrightarrow I_D = 0$

* If $V_{GS} < V_t$

* Assume saturation:

$$\longrightarrow I_D = \frac{K_p}{2}(V_{GS} - V_t)^2$$

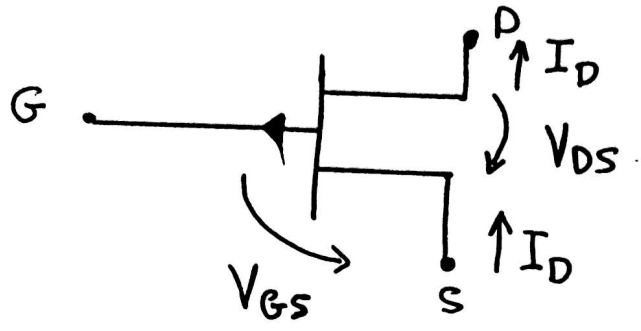
Check $\longrightarrow$ $V_{DS} \leq V_{GS} - V_t$ or $V_{GD} \geq V_t$

* If $V_{DS} > V_{GS} - V_t$ or $V_{GD} < V_t$: assume Triode

$$I_D = \frac{K_p}{2}\left[2(V_{GS} - V_t)V_{DS} - V_{DS}^2\right]$$

Check $\longrightarrow$ $V_{DS} > V_{GS} - V_t$ or $V_{GD} < V_t$

* P channel JFET DC analysis:



I_{DSS} = ⌐

V_P = ⌐

↓

(+Ve)

If $V_{GS} \geq V_P \longrightarrow$ JFET off $\longrightarrow I_D = 0$

* If $V_{GS} < V_P$:

* Assume Saturation:

$$\longrightarrow I_D = \frac{I_{DSS}}{V_P^2} (V_{GS} - V_P)^2$$

Check $\longrightarrow V_{DS} \leq V_{GS} - V_P$

or $\longrightarrow V_{GD} \geq V_P$

* If $V_{DS} > V_{GS} - V_P$ or $V_{GD} < V_P$:

$$\longrightarrow I_D = \frac{I_{DSS}}{V_P^2} \left[2(V_{GS} - V_P) V_{DS} - V_{DS}^2 \right]$$

Check $\longrightarrow V_{DS} > V_{GS} - V_P$

$\longrightarrow V_{GD} > V_P$

Pb

Advanced MOSFET devices has:

$$I_D = \frac{k_n}{2} (V_{GS} - V_t)^{\alpha}$$

Determine the transconductance $g_m = ?$

Soln

$$g_m = \frac{\partial I_D}{\partial V_{GS}}$$

$$g_m = \alpha \frac{k_n}{2} (V_{GS} - V_t)^{\alpha - 1} \cdot (1)$$

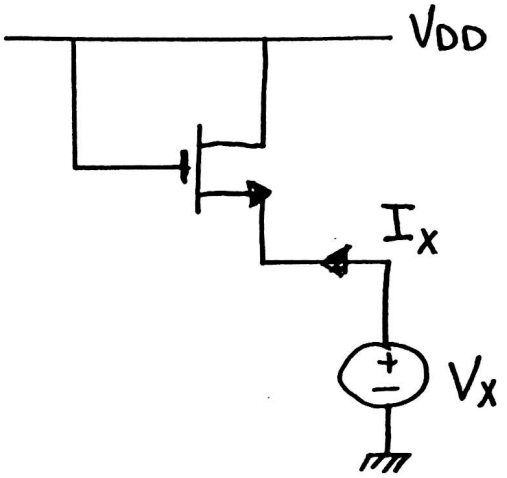
$$g_m = \alpha \cdot \frac{k_n}{2} (V_{GS} - V_t)^{\alpha} \cdot \frac{1}{V_{GS} - V_t}$$

$$g_m = \frac{\alpha I_D}{V_{GS} - V_t}$$

Pb

Sketch I_x as a function of V_x. Assume V_x goes from $0 \rightarrow V_{DD}$. Determine at what values of V_x the device changes its region of operation.

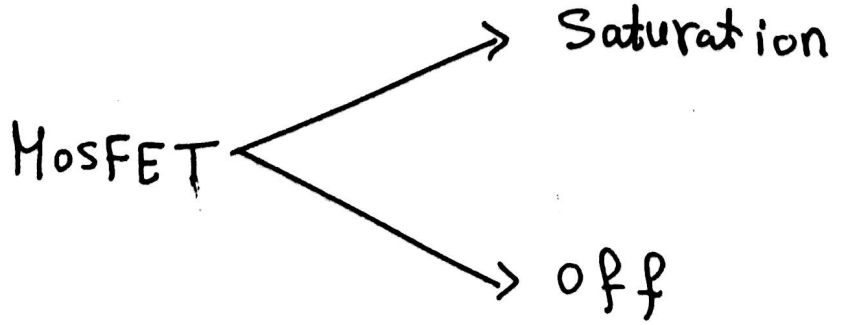
a]



Soln this is n-channel mosfet has V_t = +ve value

the gate is connected to drain $\Rightarrow V_{GD} = 0$

So, $V_{GD} < V_t \Rightarrow$ the above MOSFET Cannot be in Triode region.



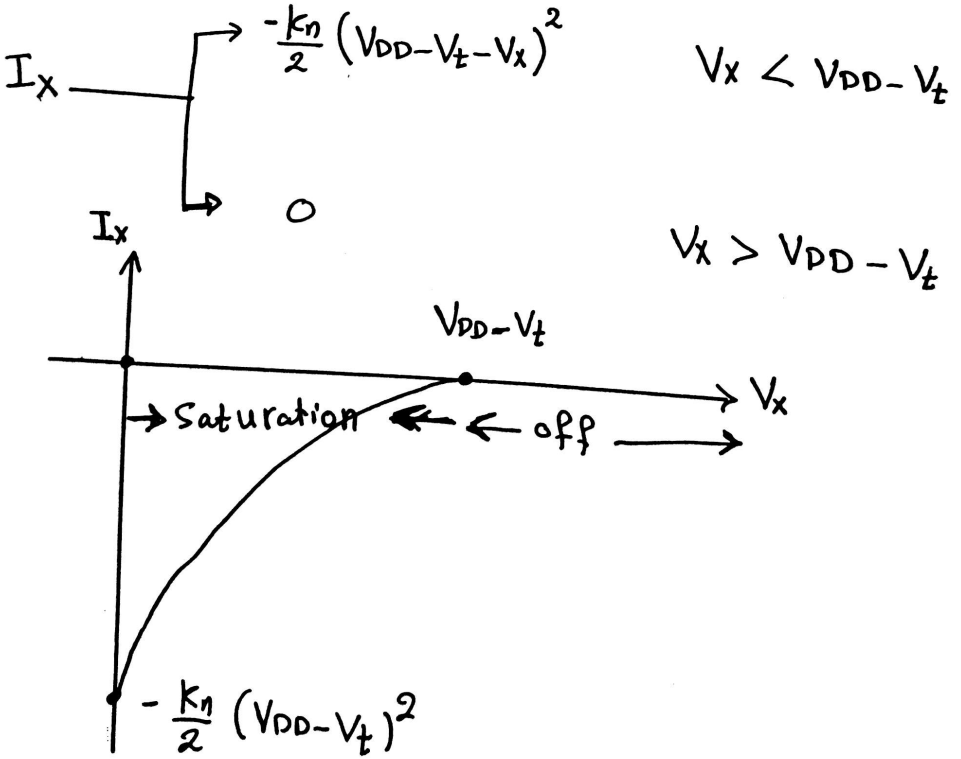
MOSFET ON (Saturation):

$$V_{GS} > V_t \longrightarrow V_{DD} - V_X > V_t$$

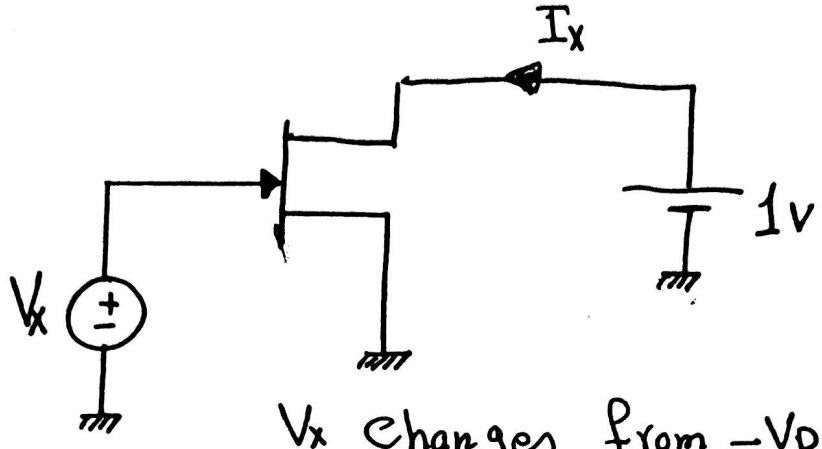
$$\boxed{V_X < V_{DD} - V_t}$$

In this case $I_X = -I_D = -\frac{k_n}{2}(V_{GS} - V_t)^2$

$$I_X = -\frac{k_n}{2}\left[V_{DD} - V_t - V_X\right]^2$$



b]



V_x changes from $-V_{DD} \rightarrow 0$, $-V_{DD} < V_p < -1$

Soln

this is n-channel JFET with $V_p = -Ve$

$V_{GS} = V_x$ ⟶ $V_x \leq V_p$ JFET off

⟶ $V_x > V_p$ JFET ON

JFET(ON) : $V_x > V_p$:

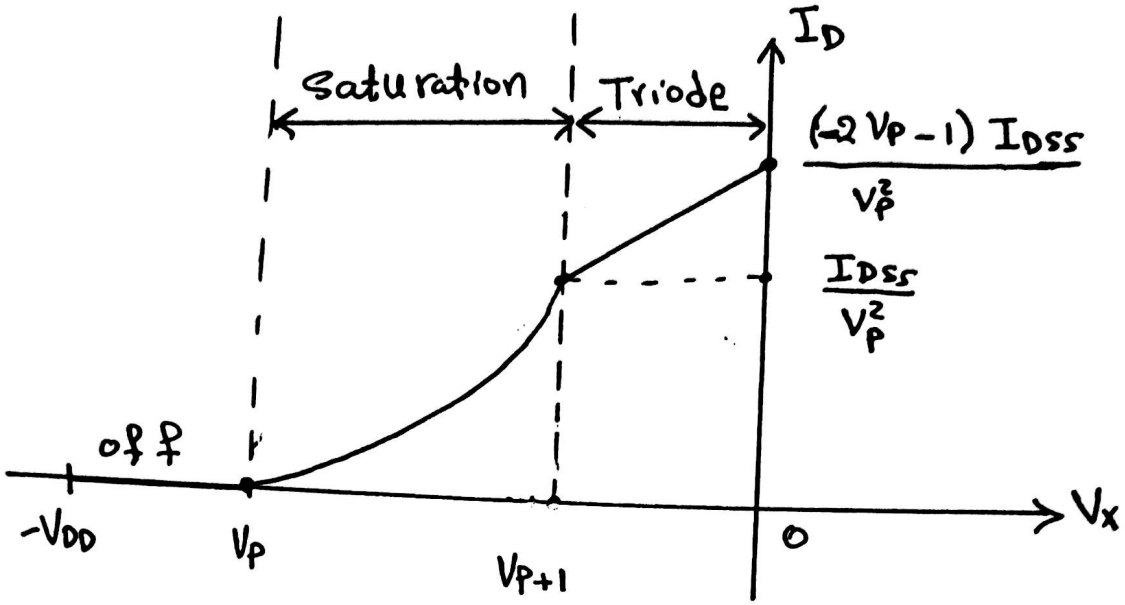
Saturation: $V_{GD} \leq V_p \rightarrow V_x - 1 \leq V_p \rightarrow \underline{V_x \leq V_p + 1}$

$$I_x = I_D = \frac{I_{DSS}}{V_p^2}(V_{GS} - V_p)^2 = \frac{I_{DSS}}{V_p^2}(V_x - V_p)^2$$

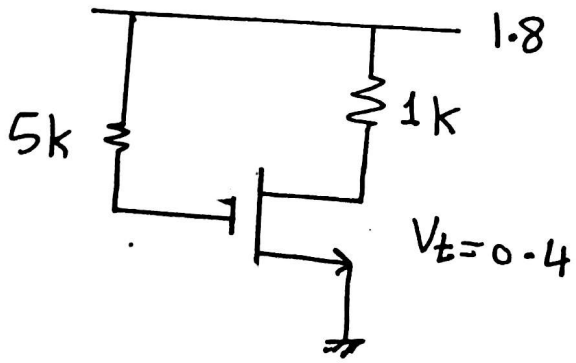
$\Rightarrow V_x > V_p + 1$: Triode

$$I_x = I_D = \frac{I_{DSS}}{V_p^2}\left[2(V_{GS} - V_p)V_{DS} - V_{DS}^2\right]$$

$$I_x = \frac{I_{DSS}}{V_p^2}\left[2(V_x - V_p) - 1\right]$$

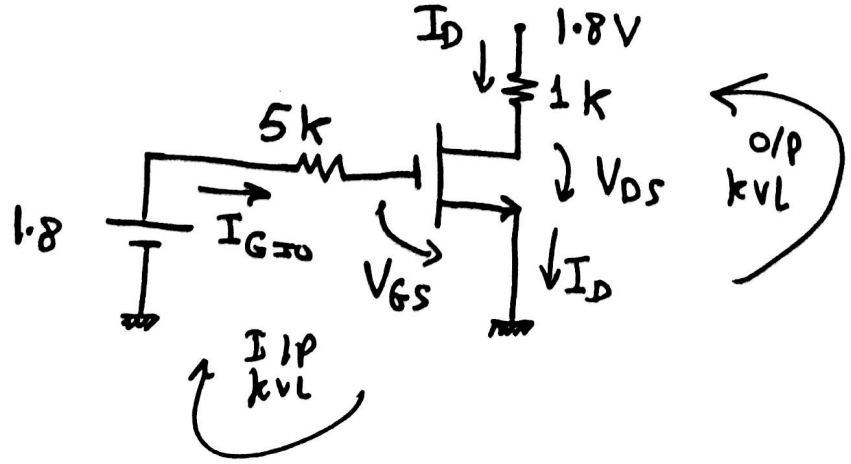


Pb



* Determine the value of k_n to remain in saturation.

Soln



to remain in saturation :

$$V_{DS} \geq V_{GS} - V_t$$

from o/p KVL — from i/p KVL

I/P KVL :

$$V_{GS} = 1.8\ V$$

O/P KVL :

$$-1.8 + I_D + V_{DS} = 0 \longrightarrow V_{DS} = 1.8 - I_D$$

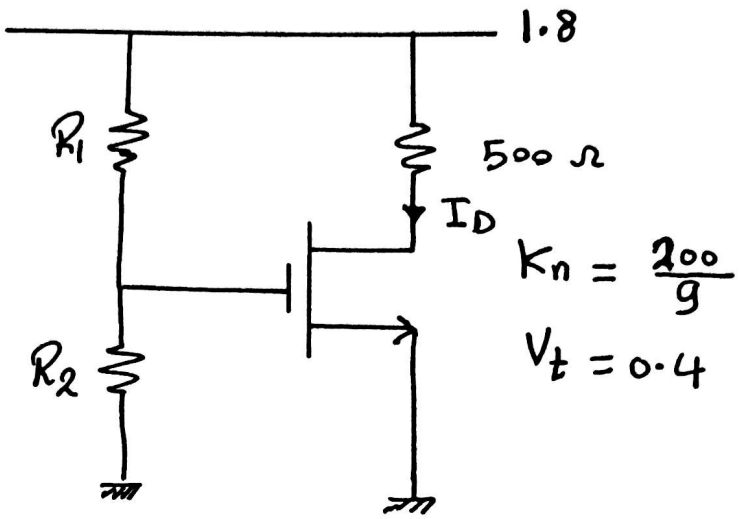
$$V_{DS} \geq V_{GS} - 0.4$$

$$1.8 - I_D \geq 1.8 - 0.4 \rightarrow I_D \leq 0.4$$

$$\frac{k_n}{2}(V_{GS} - V_t)^2 \leq 0.4$$

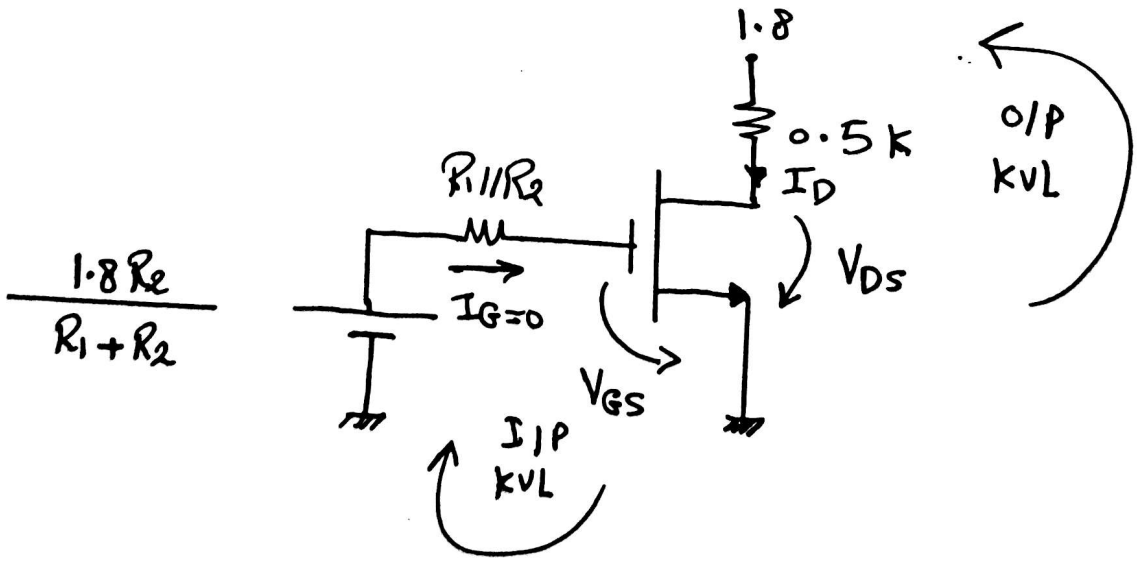
$$k_n \leq \frac{2 * 0.4}{(1.8-0.4)^2} \Rightarrow k_n \leq 0.408$$

Pb



* We wish to desig the circuit for a drain current of 1mA. Input impedance at Least 20kΩ.

Soln



* assume saturation:

$$I_D = \frac{k_n}{2}(V_{GS} - V_t)^2$$

$$1 = \frac{100}{9}(V_{GS} - 0.4)^2 \longrightarrow V_{GS} = 0.7$$

I/P KVL:

$$\frac{1.8 R_2}{R_1 + R_2} = 0.7 \longrightarrow \frac{R_1}{R_2} = \frac{11}{7}$$

Check: o/p KVL:

$$-1.8 + 0.5(1) + V_{DS} = 0 \rightarrow V_{DS} = 1.3$$

$$V_{GS} - V_t = 0.7 - 0.4 = 0.3$$

$\therefore V_{DS} > V_{GS} - V_t \rightarrow$ True assumption.

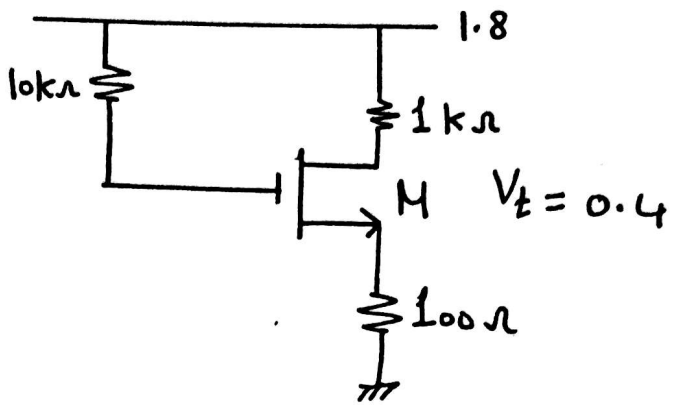
$$R_i \geq 20k \longrightarrow \frac{R_1 R_2}{R_1 + R_2} \geq 20, \quad R_1 + R_2 = \frac{1.8 R_2}{0.7}$$

$R_i = R_1 // R_2$

$$\therefore \frac{0.7 R_1}{1.8} \geq 20 \longrightarrow R_1 \geq 51.42$$

let $R_1 = 52\,k\Omega$, $R_2 = \frac{7}{11}(52) \simeq 33\,k\Omega$

Pb



Calculate the maximum transconductance that M can provide without going into triode region

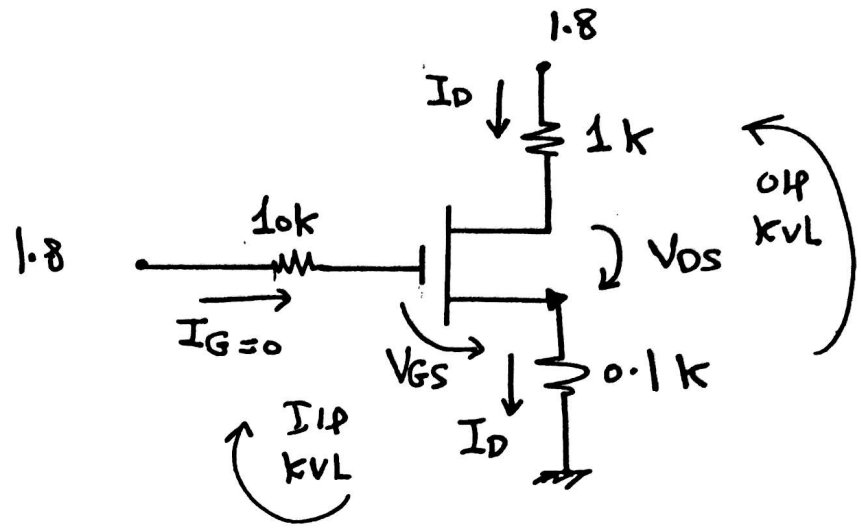
Soln

$$g_m = k_n (V_{GS} - V_t)$$

$$I_D = \frac{k_n}{2} (V_{GS} - V_t)^2 \Rightarrow k_n = \frac{2 I_D}{(V_{GS} - V_t)^2}$$

$$g_m = \frac{2 I_D}{V_{GS} - V_t} = \frac{2 I_D}{V_{GS} - 0.4}$$

$$g_{m|_{max}} = \frac{2 I_{D max}}{V_{GS|_{min}} - 0.4}$$



* to remain in Saturation:

$$V_{DS} \geq V_{GS} - V_t$$

V_{DS} ↓ O/P KVL

V_{GS} ↓ I/P KVL

I/P KVL:

$$-1.8 + V_{GS} + 0.1\, I_D = 0$$

$$\boxed{V_{GS} = 1.8 - 0.1\, I_D} \longrightarrow (1)$$

O/P KVL:

$$-1.8 + I_D + V_{DS} + 0.1\, I_D = 0$$

$$\boxed{V_{DS} = 1.8 - 1.1\, I_D} \longrightarrow (2)$$

$V_{DS} \geq V_{GS} - V_t$

$\Longrightarrow$ From (1) & (2)

$1.8 - 1.1 I_D \geq 1.8 - 0.1 I_D - 0.4$

$I_D \leq 0.4 \longrightarrow I_{D_{max}} = 0.4$

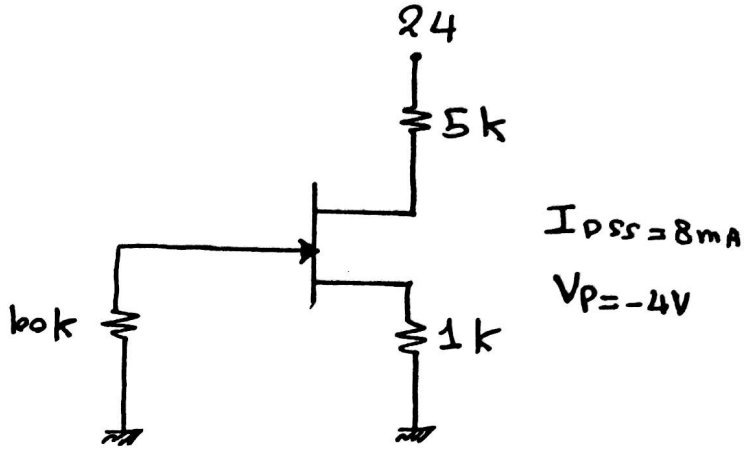
From (1) $\longrightarrow V_{GS_{min}} = 1.8 - 0.1 I_{D_{max}}$

$V_{GS_{min}} = 1.8 - 0.1(0.4) = 1.76$

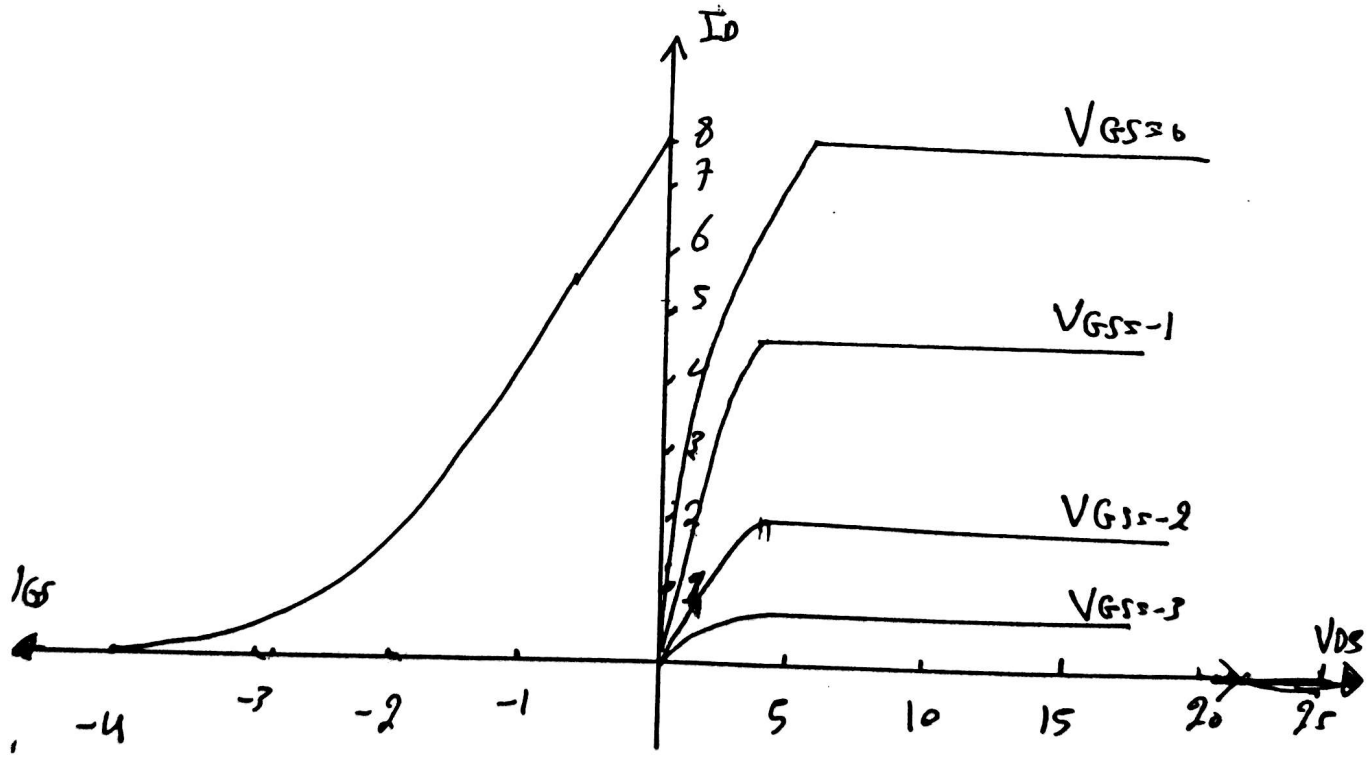
$$g_{m|_{max}} = \frac{2 I_{D_{max}}}{V_{GS_{min}} - 0.4}$$

$$g_{m|_{max}} = \frac{2(0.4)}{1.76 - 0.4} = 0.588 \text{ mA/V}$$

Pb



Determine the Q-Point using the given transfer Characteristics and Identify the operating mode

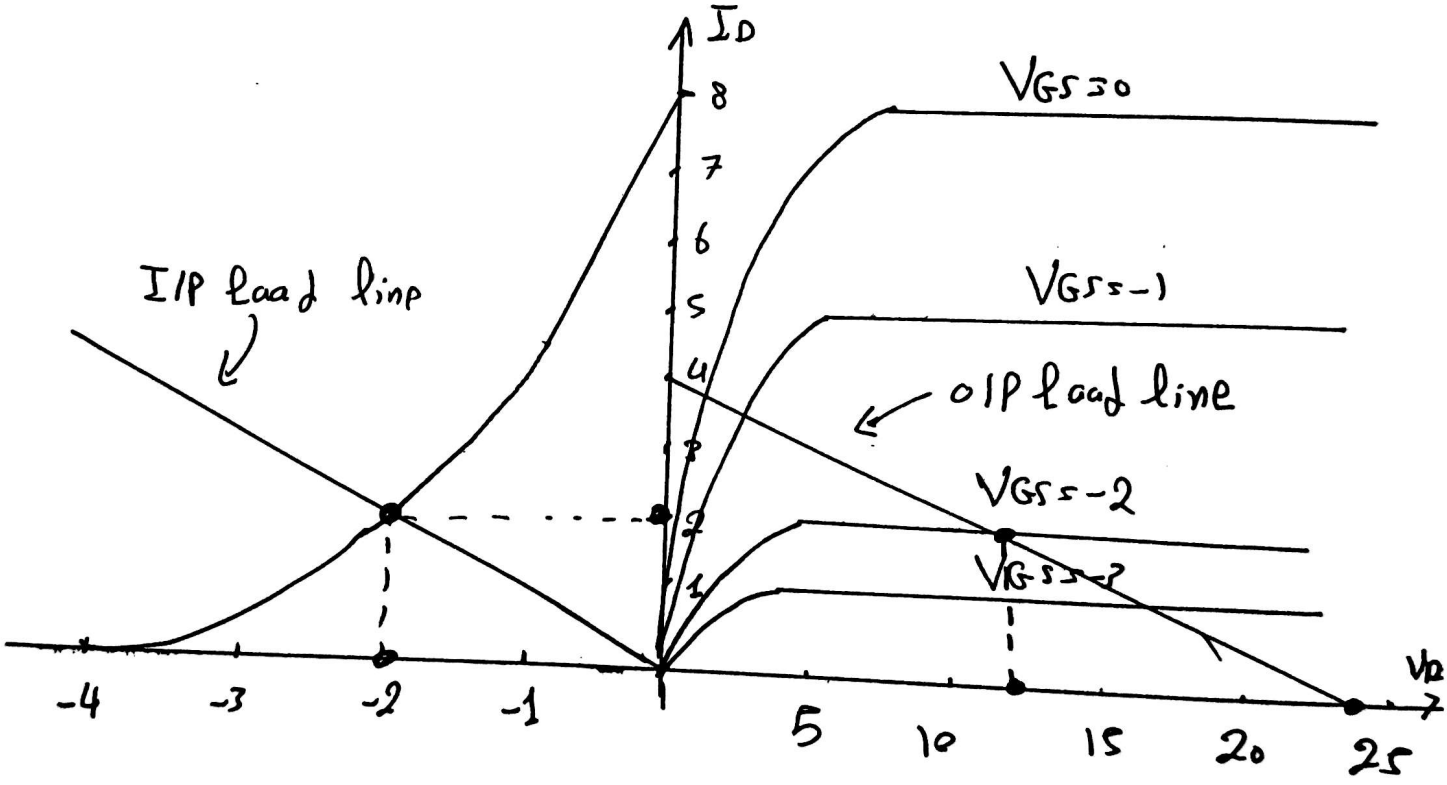


Soln

I/P KVL: $V_{GS} + I_D = 0 \Rightarrow \boxed{I_D = -V_{GS}} \Rightarrow$ I/P load line equation

O/P KVL: $-24 + 5I_D + V_{DS} + I_D = 0$

$$\boxed{I_D = \frac{24 - V_{DS}}{6}} \Rightarrow$$ O/P load line equation

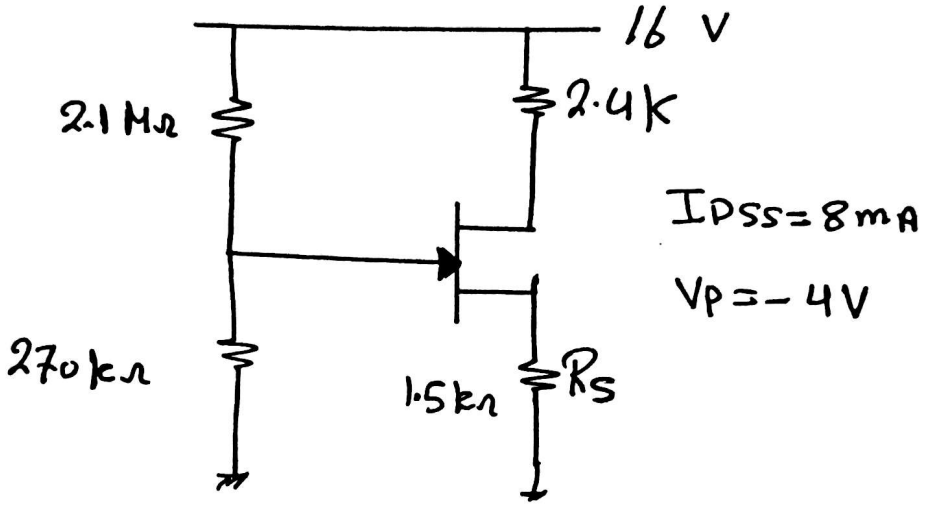


$V_{GS} = -2\,V$, $I_D = 2\,mA$, $V_{DS} = 12\,V$

$V_{GS} - V_P = 2\,V$, $V_{DS} > V_{GS} - V_P \Rightarrow$ Saturation

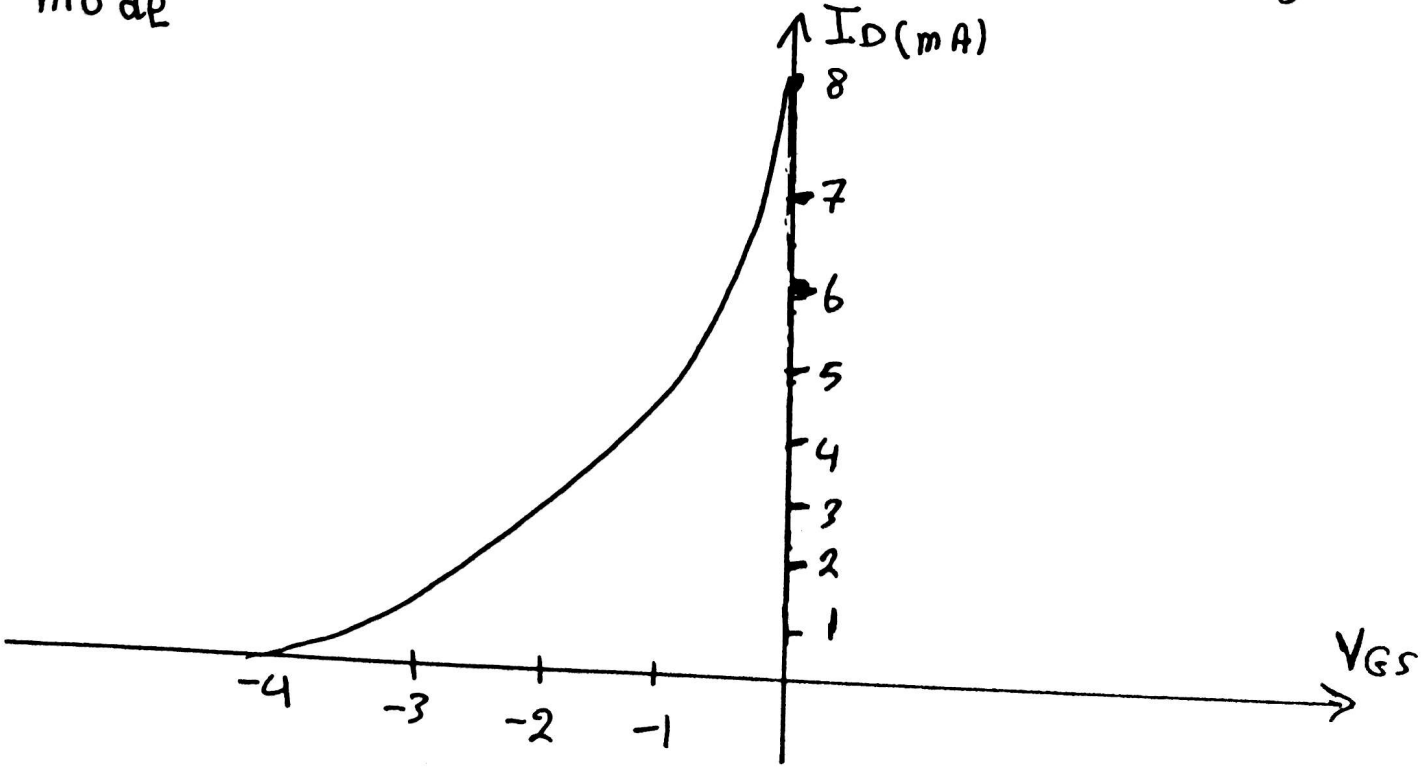
Note : Graphical solution is very important

Pb



a]

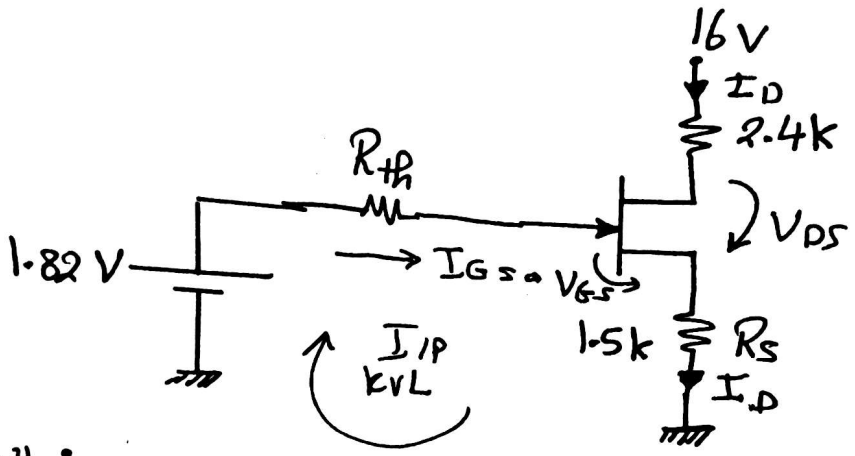
Determine V_{GS} and Q-Point using the given transfer characteristics and Identify the operating mode



Take thevinin equivalent

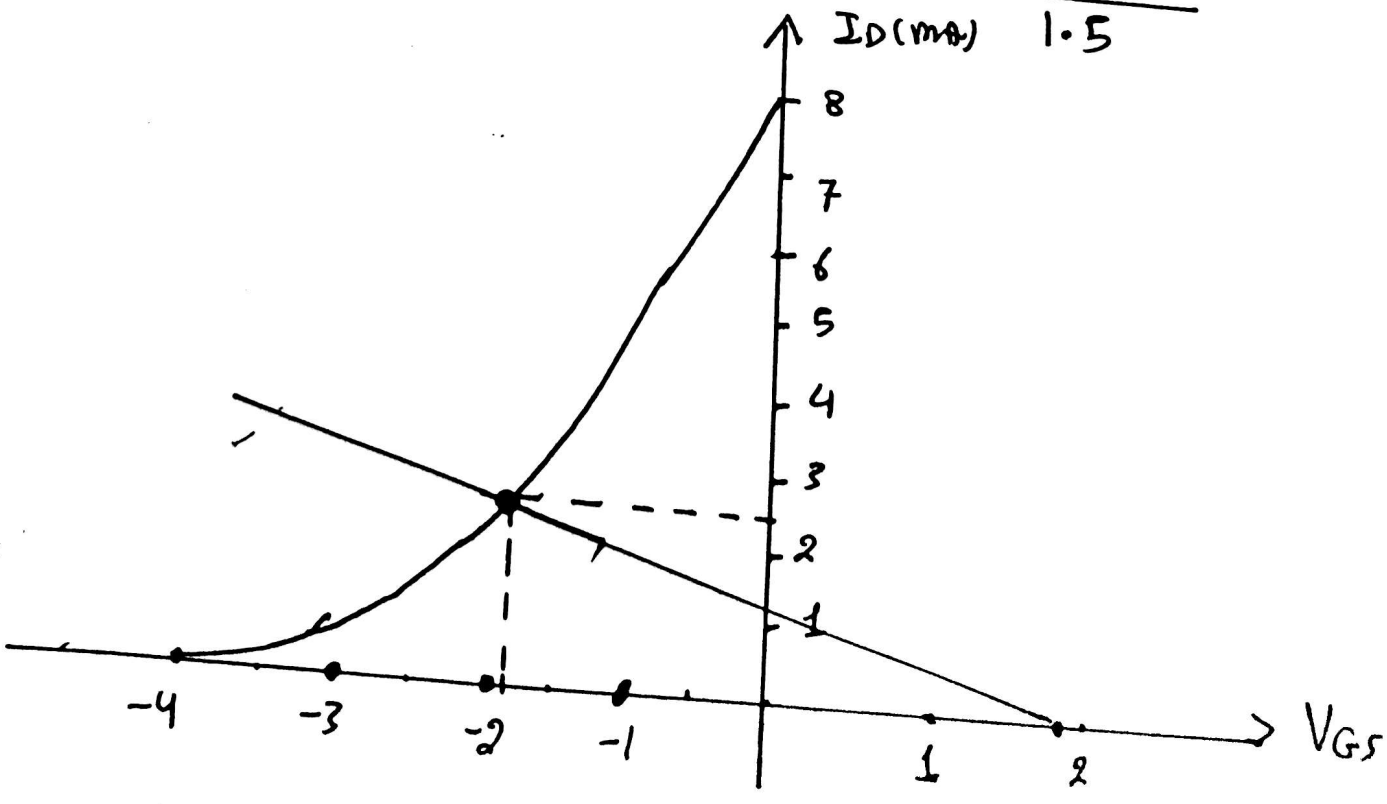
$R_{th} = 2.1\,M\Omega \,//\, 270\,k\Omega$

$V_{th} = 16 \dfrac{0.27}{0.27 + 2.1} = 1.82$ Volt



I_P KVL :

$-1.82 + V_{GS} + 1.5\, I_D = 0 \Rightarrow I_D = \dfrac{1.82 - V_{GS}}{1.5}$



$V_{GS} \simeq -1.8$ Volt

$I_D \simeq 2.4$ mA

O/P KVL :

$$-16 + 2.4(2.4) + V_{DS} + 1.5(2.4) = 0$$

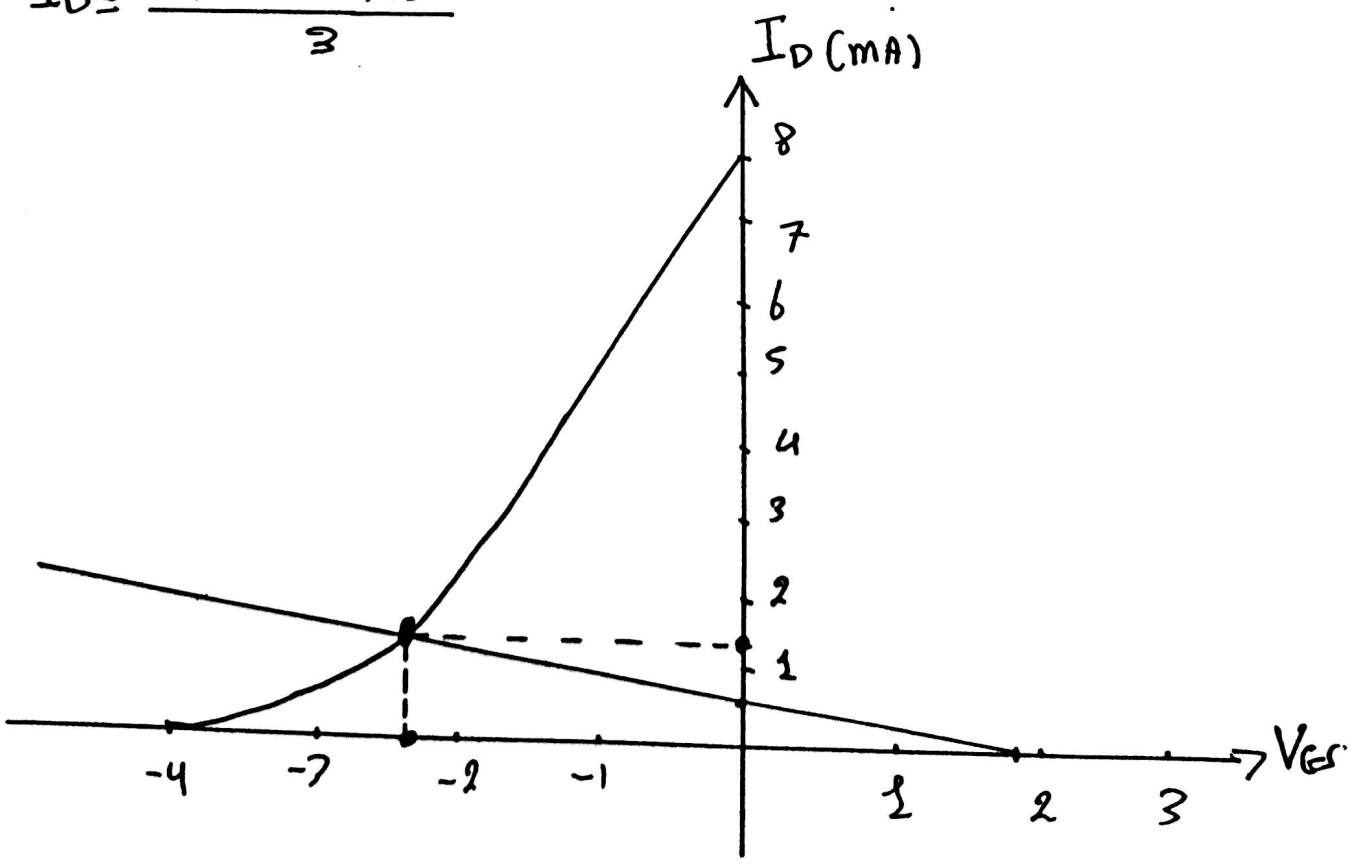
$\therefore V_{DS} = 6.64$ Volt

$V_{GS} - V_P = -1.8 + 4 = 2.2$ Volt

$V_{DS} > V_{GS} - V_P \Rightarrow$ We operates at Saturation

b) Repeat the Problem If $R_S =$ ~~3K~~ Ω (doubled)

$$I_D = \frac{1.82 - V_{GS}}{3}$$



$I_D = 1.2\ mA$, $V_{GS} = -2.4\ Volt$

Increasing $R_S \Rightarrow$ Decreasing I_D

o/p KVL

$$-16 + 2.4(1.2) + V_{DS} + 3(1.2) = 0$$

$$V_{DS} = 9.52$$

$$V_{GS} - V_P = -2.4 + 4 = 1.6$$

$V_{DS} > V_{GS} - V_P \Rightarrow$ Saturation

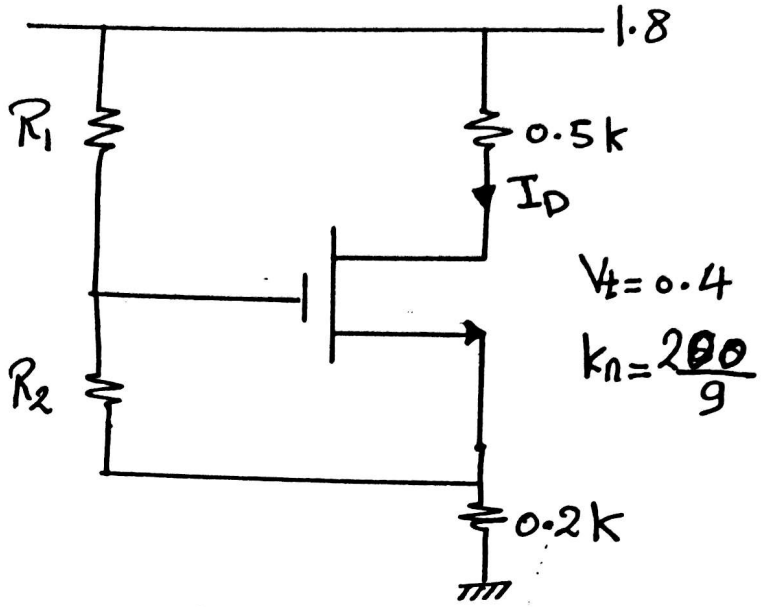
Increasing R_S make us operates in saturation.

* ملاحظة: ممكن يطلب منك في الامتحان تحل بطريقتين

(1) Analytical

(2) Graphical

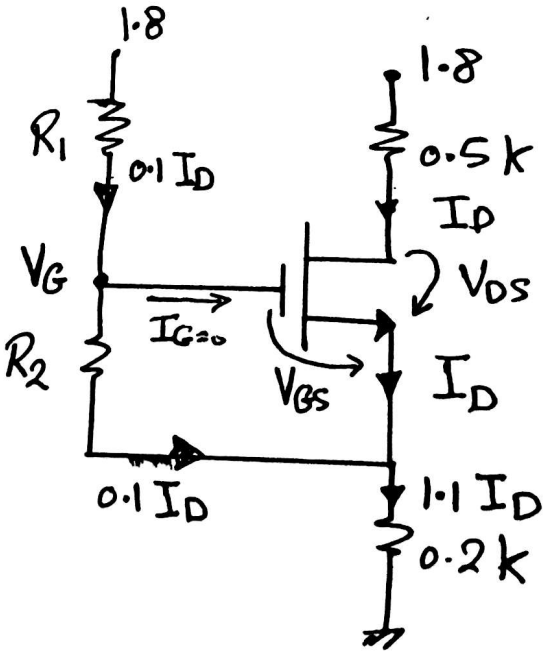
Pb



the current moving through R_2 is one-tenth of I_D

Calculate values of R_1 and R_2 so that $I_D = 0.5$ mA

Soln



If we calculate V_G then we can get R_1 & R_2.

Assume saturation:

$$I_D = \frac{k_n}{2}(V_{GS} - V_t)^2$$

$$I_D = \frac{100}{9}(V_{GS} - 0.4)^2$$

$$0.5 = \frac{100}{9}(V_{GS} - 0.4)^2$$

$$V_{GS} = 0.612\ V$$

$$V_S = 1.1 I_D * 0.2 = 1.1(0.5)(0.2) = 0.11\ V$$

$$V_{GS} = V_G - V_S = V_G - 0.11 = 0.612 \Rightarrow V_G = 0.722\ V$$

Check assumption

o/p kVL: $-1.8 + 0.5(0.5) + V_{DS} + 0.2(1.1 * 0.5) = 0$

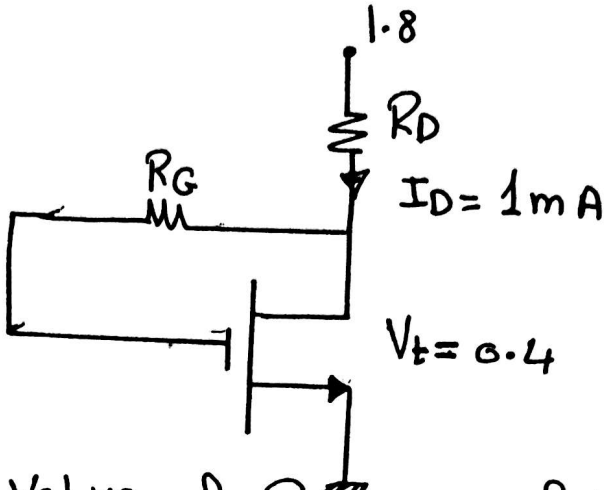
$$V_{DS} = 1.44\ ,\ V_{GS} - V_t = 0.212$$

$\therefore V_{DS} > V_{GS} - V_t \longrightarrow$ True assumption

$$R_1 = \frac{1.8 - V_G}{0.1 I_D} = \frac{1.8 - 0.722}{0.1(0.5)} = 21.56\ k\Omega$$

$$R_2 = \frac{V_G - V_S}{0.1 I_D} = \frac{0.612}{0.1(0.5)} = 12.24\ k\Omega$$

Pb



Calculate the value of R_D such that $g_m = \frac{1}{100}\,\Omega^{-1}$

Soln

Note: gate is direct connected to drain

$V_{GD} = 0 \Rightarrow V_{GD} < V_t \longrightarrow$ **Saturation**

$$g_m = k_n (V_{GS} - V_t) = \frac{2 I_D}{V_{GS} - V_t}$$

$$0.01 = \frac{2 * 10^{-3}}{V_{GS} - 0.4} \Rightarrow V_{GS} = 0.6\ V$$

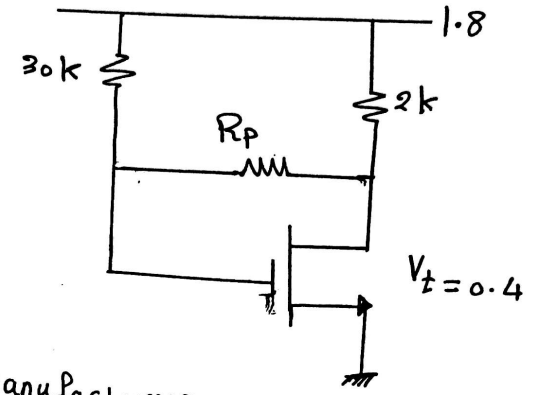
$$V_{DS} = V_{GS} = 0.6\ V$$

o/p KVL:

$$-1.8 + R_D + 0.6 = 0 \longrightarrow R_D = 1.8 - 0.6$$

$$R_D = 1.2\ k\Omega$$

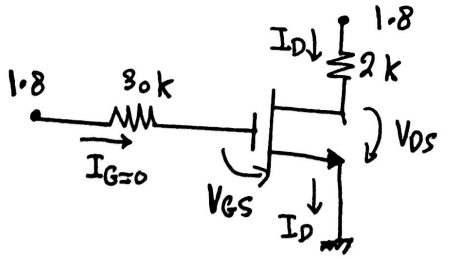
Pb



Due to a manufacturing error, a parasitic resistor Rp has appeared in the circuit. We know that the circuit samples free from this error exhibit $V_{GS} = V_{DS} + 100mV$. whereas defective samples exhibit $V_{GS} = V_{DS} + 50mV$. Determine $k_n = ?$ & $R_p = ?$

Soln

* Samples free from this error ⟶ Rp not exist
* Defective samples ⟶ Rp exist



$V_{GS} = V_{DS} + 0.1 \longrightarrow V_{GD} = 0.1 < V_t \longrightarrow$ Saturation

I/P KVL $\longrightarrow V_{GS} = 1.8\,V$

$V_{DS} = V_{GS} - 0.1 = 1.7\,V$

O/P KVL :

$-1.8 + 2I_D + 1.7 = 0 \longrightarrow I_D = 0.05\,mA$

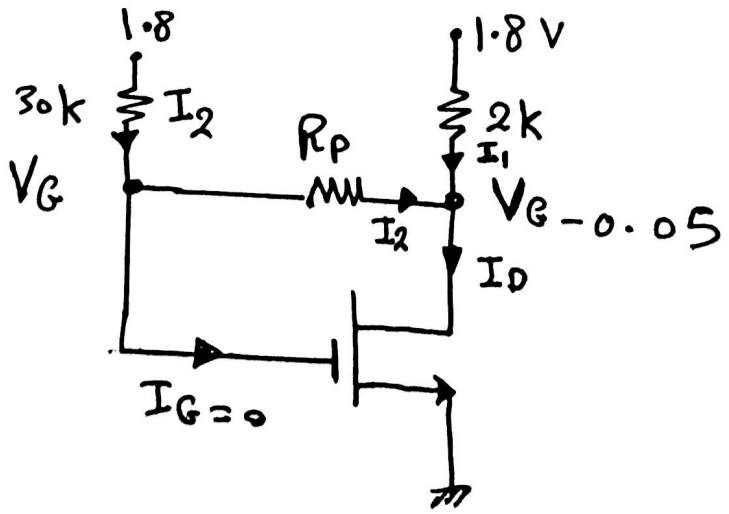
* Since mosfet operates in saturation:

$$I_D = \frac{k_n}{2}(V_{GS} - V_t)^2$$

$$0.05 = \frac{k_n}{2}(1.8 - 0.4)^2$$

$$\Rightarrow \boxed{k_n = \frac{5}{98}\ mA/V^2}$$

Defective sample: Contain R_P



$V_{GS} = V_{DS} + 0.05$

$V_{GD} = 0.05 < V_t \longrightarrow$ Saturation

$I_D = \frac{k_n}{2} (V_{GS} - V_t)^2$

$I_D = \frac{5}{196} (V_G - 0.4)^2 \longrightarrow (1)$

$I_D = I_1 + I_2 = \frac{1.8 - (V_G - 0.05)}{2} + \frac{1.8 - V_G}{30}$

$I_D = 0.985 - \frac{8}{15} V_G$

$\longrightarrow (1) \longrightarrow 0.985 - \frac{8}{15} V_G = \frac{5}{196} (V_G - 0.4)^2$

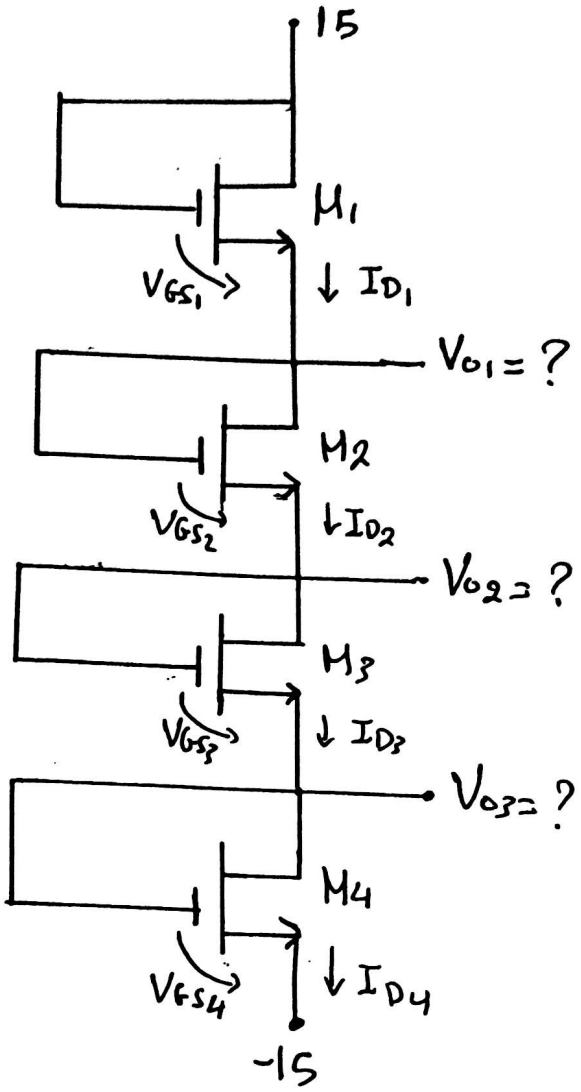
$0.985 - \frac{18}{15} V_G = \frac{5}{196} (V_G^2 + 0.4^2 - 0.8 V_G)$

Using Calculator $\longrightarrow V_G = 1.76$ Volt

$I_2 = \frac{1.8 - V_G}{30} = \frac{1.8 - 1.76}{30} = (1/750)$ mA

$R_p = \frac{0.05}{I_2} = 0.05(750) = 37.5$ kΩ

P6



* M_1 & M_4 have $K_{n_1} = 0.1\ mA/V^2$
* M_2 & M_3 have $K_{n_2} = 0.001\ mA/V^2$
* all transistors have $V_t = 2\ V$
* Find V_{o1}, V_{o2} and V_{o3}
* Comment on your answer

Soln

* all transistors have $V_{GD} = 0 > V_t$ so, all transistors operates in saturation mode.

$$I_D = \frac{K_n}{2}(V_{GS} - 2)^2$$

From circuit: $I_{D1} = I_{D2} = I_{D3} = I_{D4}$

* $I_{D1} = I_{D4}$ & (M_1 & M_4) have same $K_n \Rightarrow V_{GS1} = V_{GS4}$
* $I_{D2} = I_{D3}$ & (M_2 & M_3) " " " " $\Rightarrow V_{GS2} = V_{GS3}$

I/P KVL:

$$-15 + V_{GS1} + V_{GS2} + V_{GS3} + V_{GS4} - 15 = 0$$

$$V_{GS1} + V_{GS2} = 15 \longrightarrow (1)$$

We need other equation to get V_{GS1} & V_{GS2} = ?

$$I_{D1} = I_{D2}$$

$$\frac{K_{n1}}{2}(V_{GS1} - 2)^2 = \frac{K_{n2}}{2}(V_{GS2} - 2)^2$$

$$0.1(V_{GS1} - 2)^2 = 0.001(V_{GS2} - 2)^2$$

$$V_{GS_1} - 2 = 0.1 (V_{GS_2} - 2)$$

$$\Rightarrow V_{GS_1} - 0.1 V_{GS_2} = 1.8 \Longrightarrow (2)$$

From (1) & (2) $\longrightarrow V_{GS_1} = 3V$

$\longrightarrow V_{GS_2} = 12V$

$V_{DS_1} = V_{DS_4} = 3V$, $V_{DS_2} = V_{DS_3} = 12V$

$V_{o_1} = 15 - V_{DS_1} = 15 - 3 = 12V$

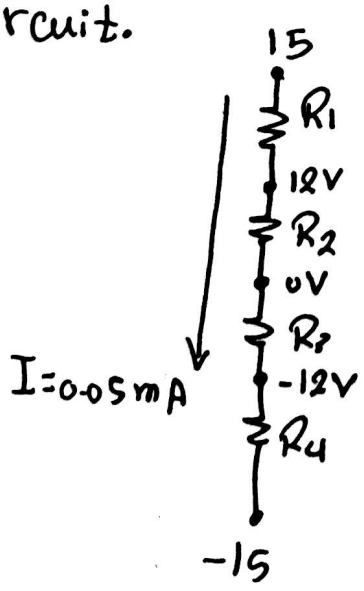
$V_{o_2} = V_{o_1} - V_{DS_2} = 12 - 12 = 0V$

$V_{o_3} = V_{o_2} - V_{DS_3} = 0 - 12 = -12V$

$I_D = \frac{1}{2}(0.1)(3-2)^2 = 0.05\ mA$

Comment

* This circuit like a resistor Voltage devider Circuit.



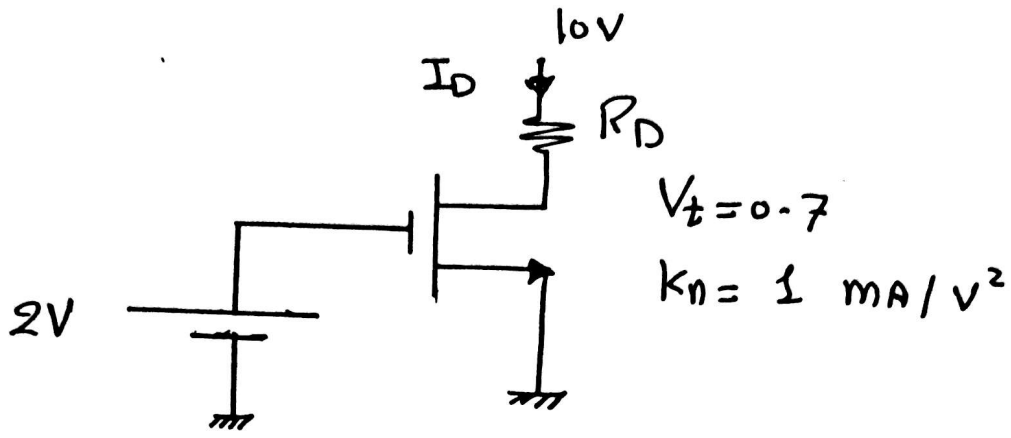
$$R_1 = \frac{15-12}{0.05} = 60\ k\Omega$$

$$R_2 = \frac{12-0}{0.05} = 240\ k\Omega$$

$$R_3 = \frac{0-(-12)}{0.05} = 240\ k\Omega$$

$$R_4 = \frac{-12-(-15)}{0.05} = 60\ k\Omega$$

Final 2014



1) Find I_D if $R_D = 10\ k\Omega$

2) If $I_D = 0.6\ mA$, then, find maximum Value of R_D to remain in Saturation

3) If $I_D = 0.6\ mA$, find optimum Value of R_D to maximize the o/p swing.

Soln

(1) assume Saturation:

$$I_D = \frac{k_n}{2}(V_{GS} - V_t)^2$$

I/P KVL $\quad V_{GS} = 2V$

$$I_D = \frac{1}{2}(2 - 0.7)^2 = 0.845\ mA$$

Check assumption (O/P KVL):

$-10 + (0.845)\,10 + V_{DS} = 0$

$V_{DS} = 1.55\ V, \quad V_{GS} - V_t = 1.3$

$V_{DS} > V_{GS} - V_t \longrightarrow$ True assumption

2] $I_D = 0.6\ mA$

* max R_D to remain in saturation = ?

to remain in saturation!

$V_{DS} \geq V_{GS} - V_t$

$V_{DS} \geq 1.3$

$10 - 0.6 R_D \geq 1.3$

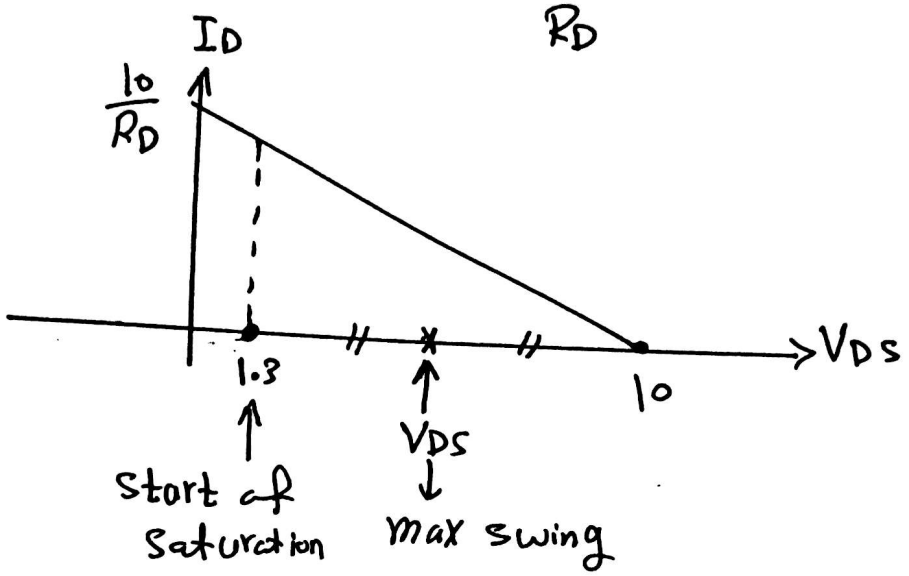
$0.6 R_D \leq 8.7$

$R_D \leq 14.5\ k$

$R_D\big|_{max} = 14.5\ k\Omega$

3] maximize o/p swing

o/p KVL $\qquad I_D = \dfrac{10 - V_{DS}}{R_D}$



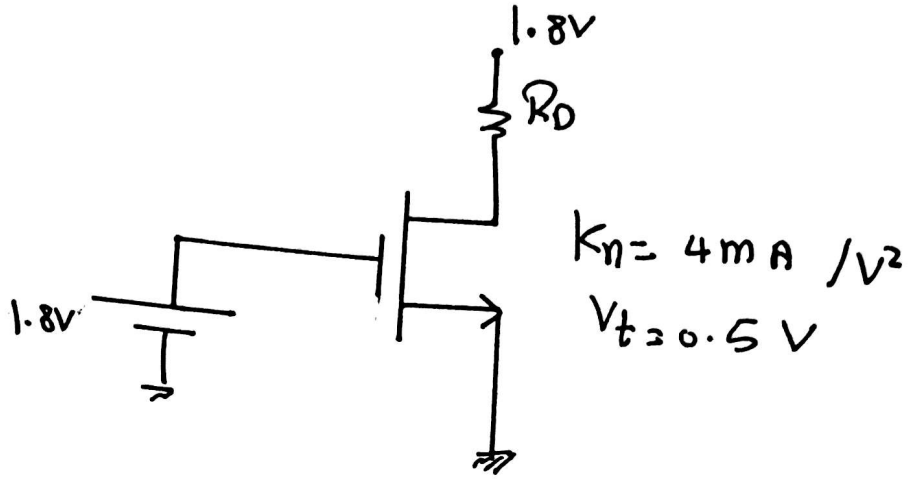
$$V_{DS}\Big|_{max\text{-}swing} = \frac{10 + 1.3}{2} = 5.65 \text{ Volt}$$

$$R_D\Big|_{max\text{-}swing} = \frac{10 - V_{DS}\big|_{max\,swing}}{0.6} = \frac{10 - 5.65}{0.6}$$

$$R_D\Big|_{max\text{-}swing} = 7.25\ k\Omega$$

"Sheet Problems"

Pb1 (Sheet3):

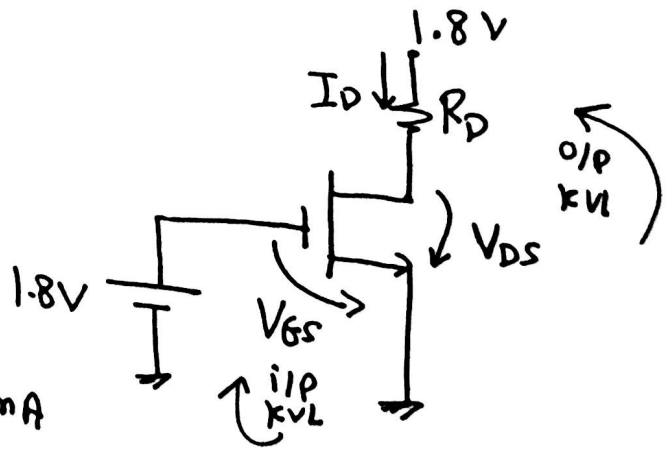


Show that the operation at the edge of saturation is obtained when $R_D = 148\,\Omega$.

Soln edge of Saturation $\Rightarrow V_{DS} = V_{OV} = V_{GS} - V_t$

I/P KVL $-1.8 + V_{GS} = 0$

$\therefore V_{GS} = 1.8\,V$



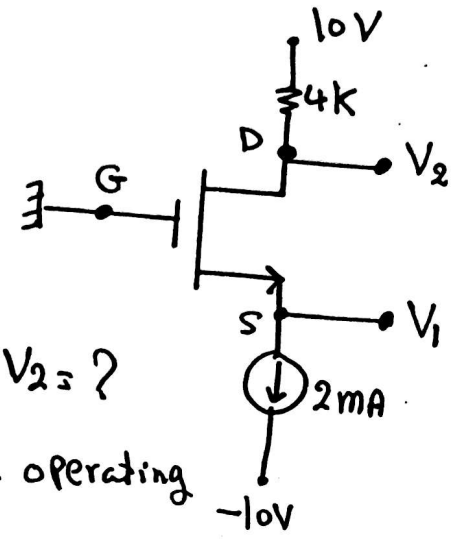
at edge $I_D = \frac{k_n}{2}(V_{GS} - V_t)^2$

$I_D = \frac{4}{2}(1.8-0.5)^2 = 3.38\,mA$

$V_{DS} = 1.8 - 0.5 = 1.3\,V$

O/P KVL $-1.8 + 3.38\,R_D + 1.3 = 0 \Rightarrow R_D \simeq 148$ *

Pb2 (Sheet 3)



$K_n = 1\ mA/V^2$

$V_t = 2\ V$

Find $V_1, V_2 = ?$

& Identify operating mode?

Soln

$I_D = 2\ mA$

assume saturation: $I_D = \frac{K_n}{2}(V_{GS} - V_t)^2$

$2 = \frac{1}{2}(V_{GS} - 2)^2 \Rightarrow V_{GS} = 4\ V$

$V_{GS} = V_G - V_S = 0 - V_S = 4V \Rightarrow V_S = -4\ V$

$\therefore V_1 = -4V$, $V_D = 10 - 4I_D = 10 - 8 = 2V$

$\therefore V_2 = 2V$

Check: $V_{DS} = V_2 - V_1 = 2 - (-4) = 6\ V$

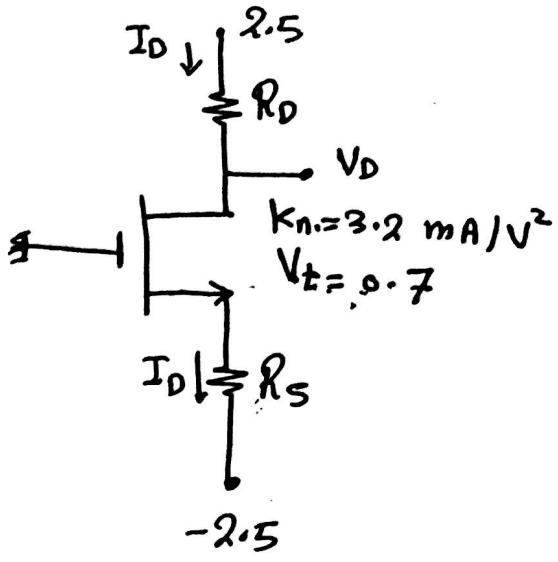
$V_{GS} - V_t = 4 - 2 = 2\ V$, $V_{DS} > V_{GS} - V_t$ ✓

Pb3 (Sheet 3) :

Justify saturation mode & find R_D & R_S so that

$I_D = 0.4\ mA$

$V_D = 0.5\ V$



Soln

Soln $V_G = 0$, $V_D = 0.5$

$V_{GD} = -0.5 < V_t \longrightarrow$ mosfet operates at saturation

$$R_D = \frac{2.5 - V_D}{I_D} = \frac{2.5 - 0.5}{0.4} = 5\ k\Omega$$

$$I_D = \frac{k_n}{2}(V_{GS} - V_t)^2 \Rightarrow 0.4 = \frac{3.2}{2}(V_{GS} - 0.7)^2$$

$V_{GS} = 1.2\ V \Rightarrow V_{GS} = V_G - V_S = -V_S$

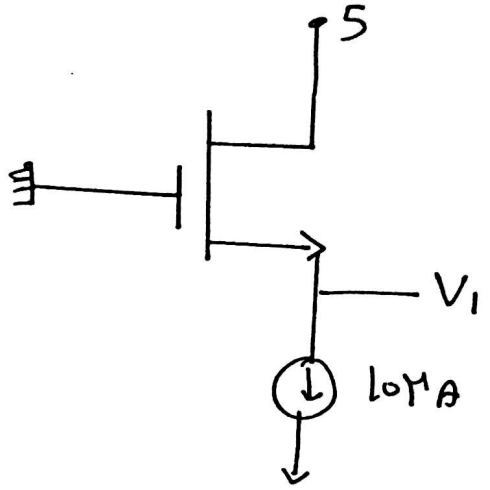
$\therefore V_S = -1.2\ V$

$$R_S = \frac{V_S - (-2.5)}{I_D} = \frac{-1.2 + 2.5}{0.4} = 3.25\ k\Omega$$

Pb4 (Sheet3):

Find labeled Voltages & Identify the operating mode. $K_n = 0.5\ mA/V^2$, $V_t = 0.8V$.

a)



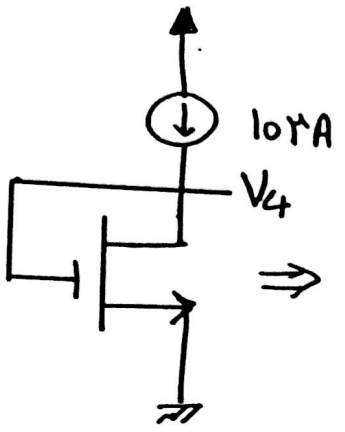
$V_G = 0$, $V_D = 5 \Rightarrow V_{GD} = -5 < V_t \Rightarrow$ We operates in saturation

$I_D = \frac{K_n}{2}(V_{GS} - V_t)^2 \Rightarrow \frac{10}{1000} = \frac{0.5}{2}(V_{GS} - 0.8)^2$

$\therefore V_{GS} = 1$ Volt $\Rightarrow V_S = V_1 = -1$ Volt *

Problem b, c exactly same as a

d)



$\Rightarrow$ operates only in saturation.

Note $G = D \Rightarrow V_{GD} = 0V < V_t \Rightarrow$ Saturation ←

$$I_D = \frac{k_n}{2}(V_{GS} - 0.8)^2 = \frac{0.5}{2}(V_{GS} - 0.8)^2$$

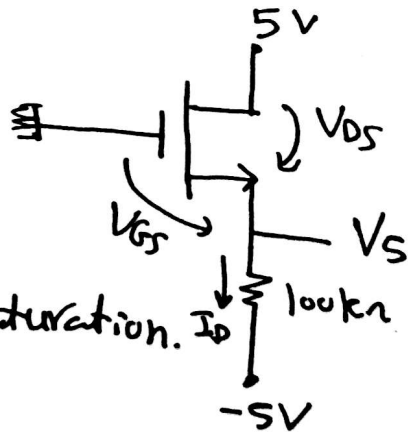
$$\frac{10}{1000} = \frac{0.5}{2}(V_{GS} - 0.8)^2 \Rightarrow V_{GS} = 1V$$

$$V_{GS} = V_G - V_S = V_G = V_D = V_4 = 1V.$$

e)

$V_{GD} = -5 < V_t$

So, we operates at saturation.



I/P KVL

$$V_{GS} + 100 I_D - 5 = 0 \Rightarrow I_D = \frac{5 - V_{GS}}{100}$$

$$I_D = \frac{k_n}{2}(V_{GS} - V_t)^2$$

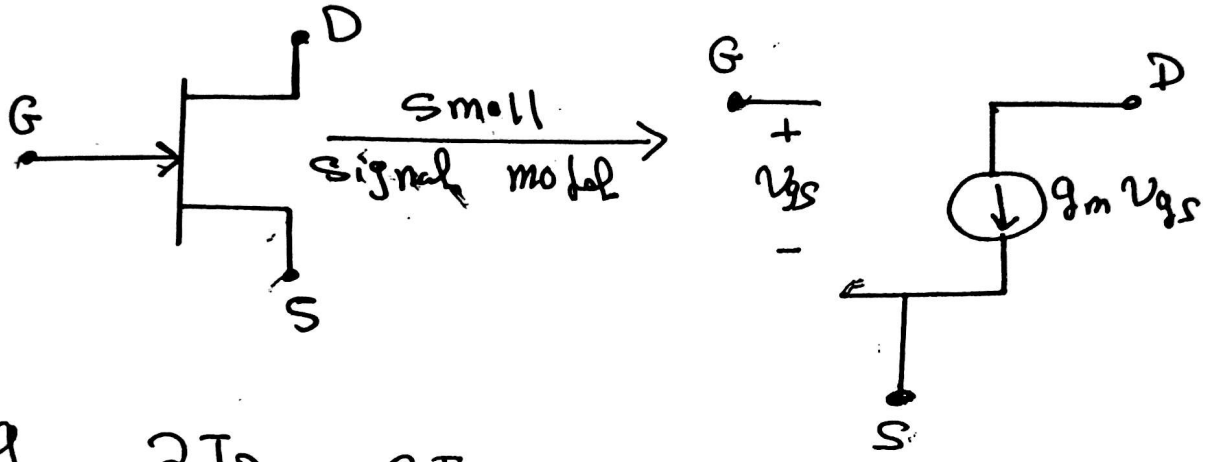
$$\frac{5 - V_{GS}}{100} = \frac{0.5}{2}(V_{GS} - 0.8)^2 \Rightarrow V_{GS} \simeq 1.2V$$

$$V_{GS} = V_G - V_S = 0 - V_S = 1.2 \Rightarrow V_S = V_S \simeq -1.2\,V$$

* AC analysis:

(* قبل ما تبتدى ذا التر ملزمة (9))

1. JFET Small signal model:

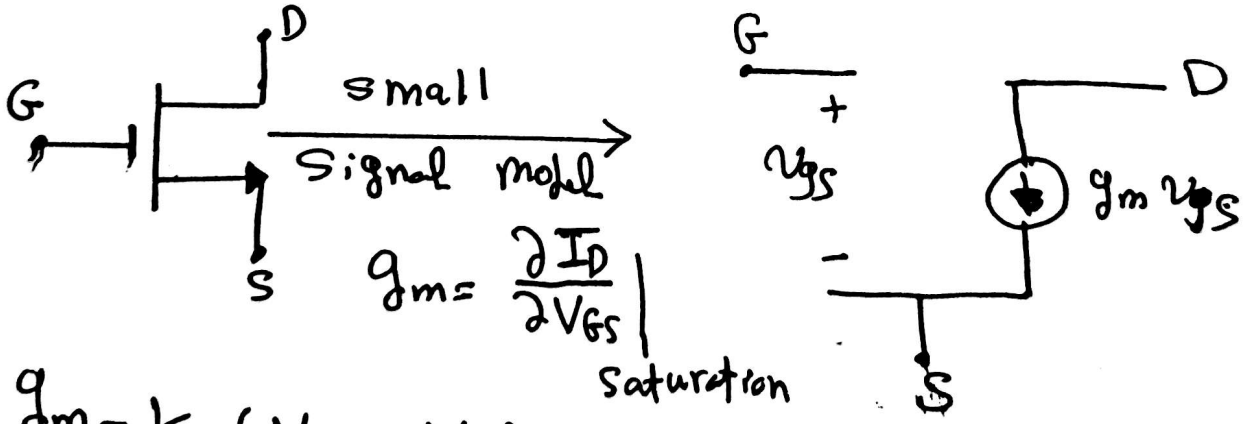


$$g_m = \left.\frac{2I_D}{2V_{GS}}\right| = \frac{2I_{DSS}}{V_P^2}(V_{GS} - V_P)$$

Saturation

↳ DC analysis

2. MOSFET Small signal model:



$$g_m = \left.\frac{\partial I_D}{\partial V_{GS}}\right|$$

Saturation

$$g_m = k_n (V_{GS} - V_t)$$

↳ DC analysis

$$g_m = \frac{2I_D}{V_{GS} - V_t} \Rightarrow (I_D, V_{GS}) \Longrightarrow \text{DC analysis}$$

* Note

* DC analysis;

* Deactivate all AC sources

* ⊣⊢ → —/—

* AC analysis;

* Deactivate all DC sources

* ⊣⊢ → S.C

* Deactivation:

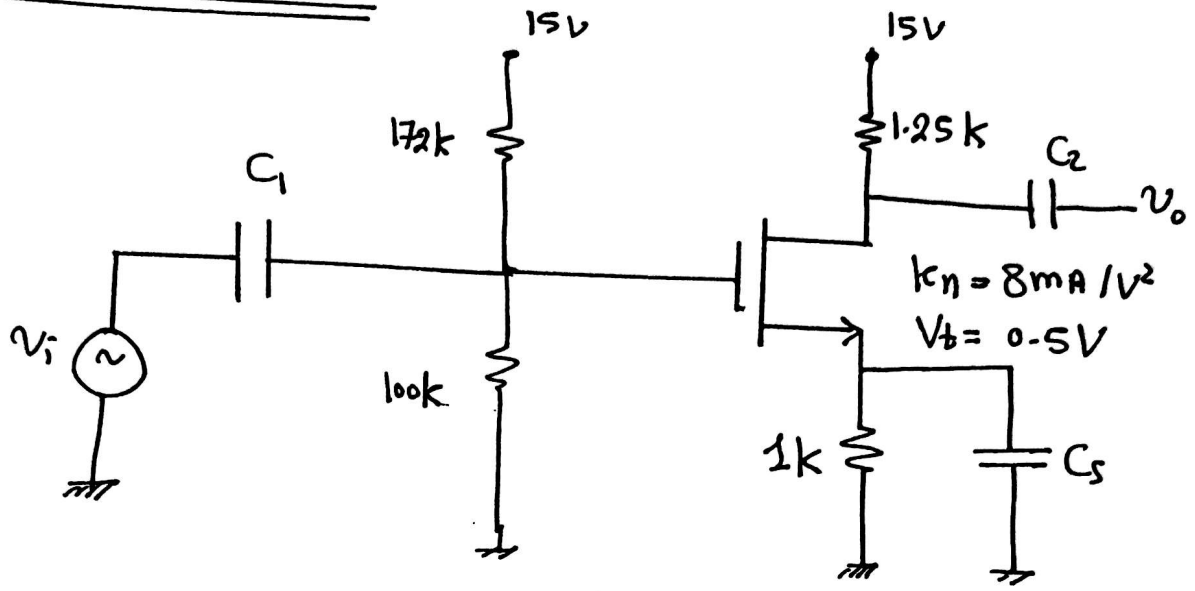
* Voltage source ⟶ short circuit

* Current source ⟶ open circuit

Steps:

1. DC analysis → V_{GS} =⌐ → g_m =⌐
2. Draw small signal model (AC analysis)
3. $A_v = \frac{v_o}{v_i}$, $A_i = \frac{i_o}{i_i}$, $R_i = \frac{V_i}{i_i}$, R_o = ⌐

P66 (Sheet 3)



Find 1) DC operating point

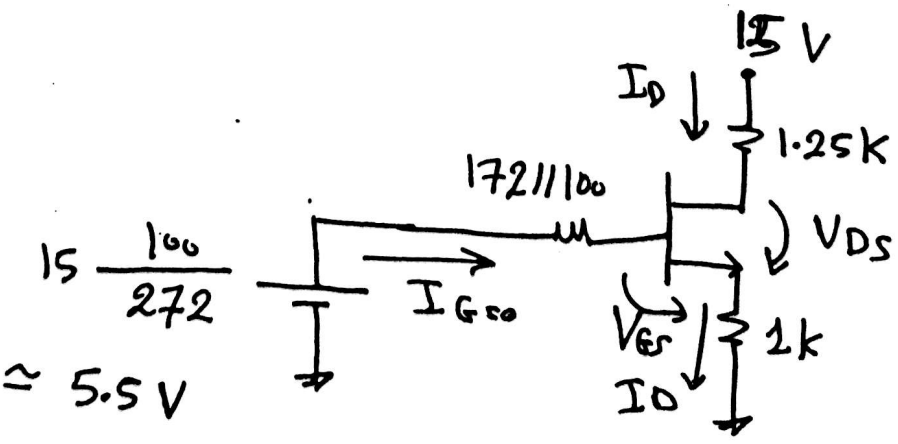
2) $A_v = \frac{v_o}{v_i}$ in dB

3) $v_o = ?$ if $v_i = 10mV$

Soln DC analysis → Deactivate all AC sources

→ all ⊣⊢ → ⊣/⊢

DC circuit :



Amplifier $\Longrightarrow$ Saturation

$$I_D = \frac{k_n}{2}(V_{GS} - V_t)^2 = 4(V_{GS} - 0.5)^2$$

I/P KVL

$$-5.5 + V_{GS} + I_D = 0 \longrightarrow I_D = 5.5 - V_{GS}$$

$$5.5 - V_{GS} = 4(V_{GS} - 0.5)^2 \Rightarrow V_{GS} = 1.5\,V$$

$$I_D = 4\,mA$$

O/P KVL

$$-15 + 4 * 1.25 + V_{DS} + 4 = 0 \longrightarrow V_{DS} = 6\,V$$

$$V_{GS} - V_t = 1\,V$$

$V_{DS} > V_{GS} - V_t$ as expected

DC operating Point

$V_{GS} = 1.5\,V$

$I_D = 4\,mA$

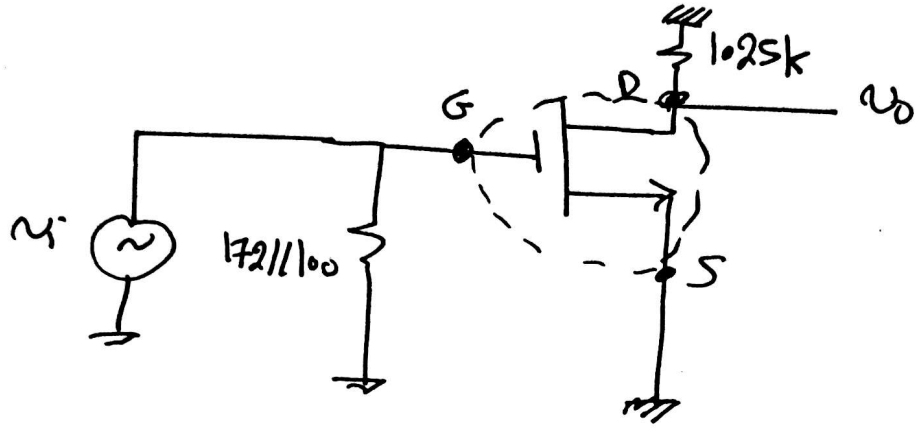
$V_{DS} = 6\,V$

$$g_m = k_n(V_{GS} - V_t) = 8 * 1 = 8\,mA/V$$

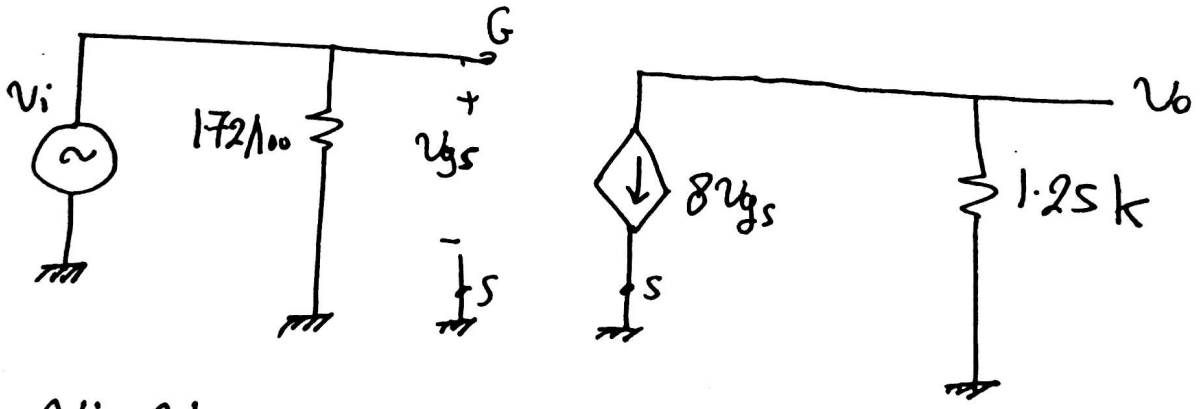
AC circuit:

1) Deactivate all DC sources

2) $\dashv\vdash \rightarrow$ S.C



Small signal circuit:

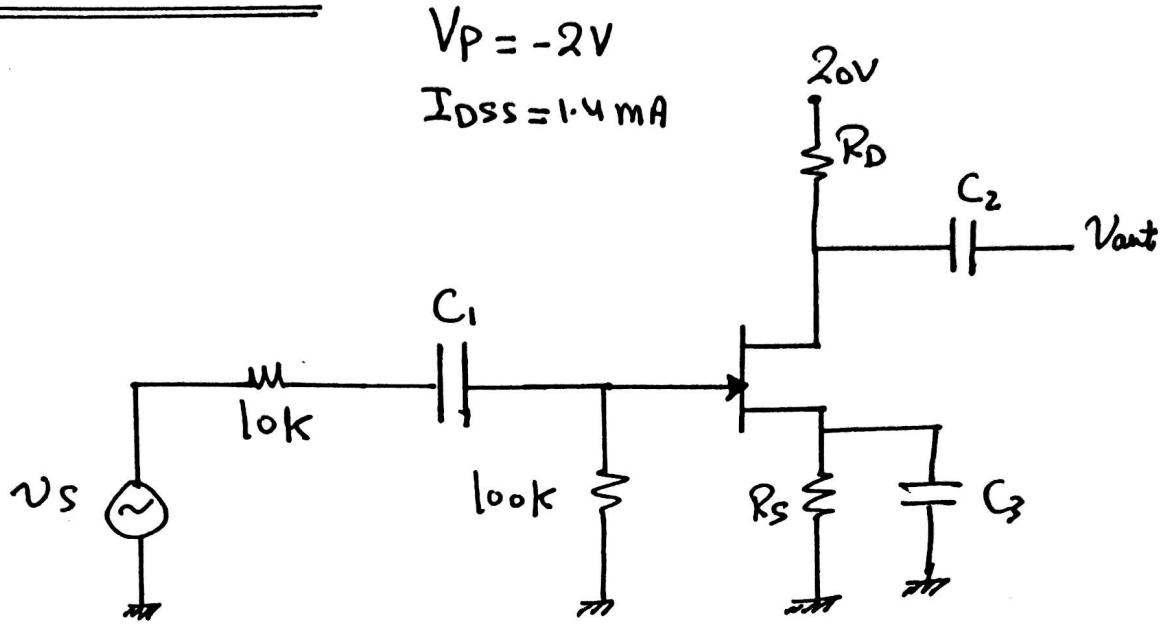


$v_i = v_{gs}$, $v_o = -10 v_{gs}$, $A_v = \frac{v_o}{v_i} = -10$

$A_v|_{dB} = 20 \log|A_v| = 20\ dB$

* $v_i = 10mV \Longrightarrow v_o = -100mV = -0.1\ V$ *

Pb5 (Sheet 2):

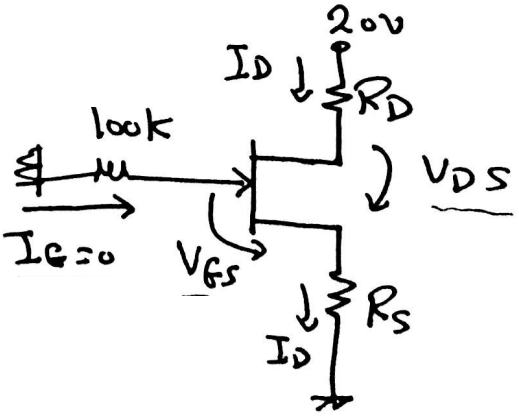


* $I_D = 0.7$ mA, $A_v = 20$ dB Find R_S & R_D

*Soln

Note that: R_S appears only in DC analysis

DC analysis:



Amplifier $\Longrightarrow$ Saturation

$$I_D = \frac{I_{DSS}}{V_P^2}(V_{GS} - V_P)^2$$

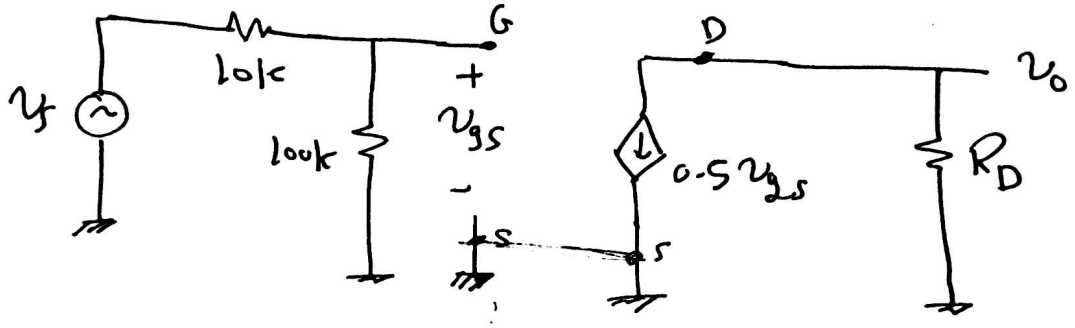
$$0.7 = \frac{1.4}{4}(V_{GS}+2)^2 \Longrightarrow V_{GS} = -0.58 \text{ volt}$$

I/P KVL:

* $V_{GS} + I_D R_S = 0 \longrightarrow R_S = \frac{-V_{GS}}{I_D} = 836.8\,\Omega$

* $g_m = \frac{2 I_{DSS}}{V_P^2} V_{OV} = 0.5\,mA/V$

* AC analysis:



* $v_o = -0.5 v_{gs} R_D$, $v_s = 110 \frac{v_{gs}}{100}$

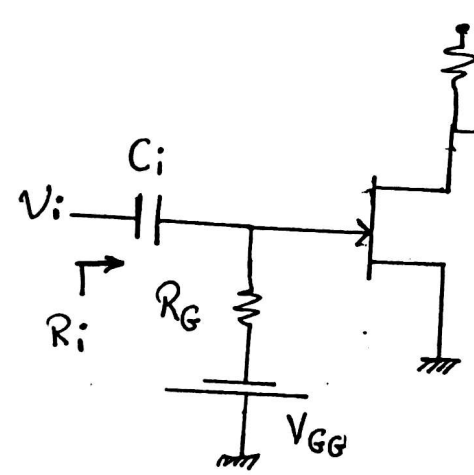
$|A_v| = \frac{0.5 R_D}{110/100} = 10 \frac{20}{20} \Longrightarrow R_D = 22\,k\Omega$

Amplifier Configurations

* Common Source :

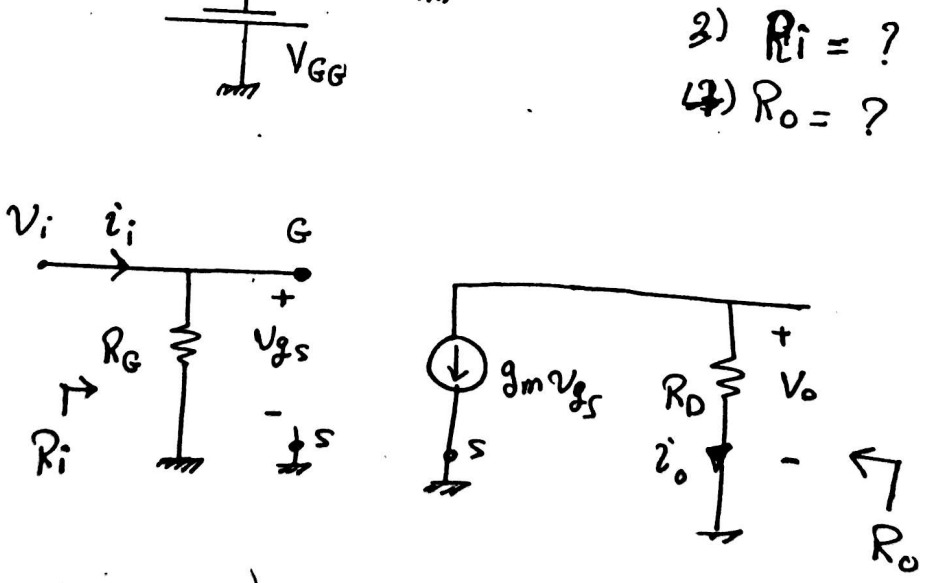
* Input at gate and output at drain
* Source is common between input & output

JFET Common Source Amplifier :



Find

1) $A_v = ?$, 2) $A_i = ?$
3) $R_i = ?$
4) $R_o = ?$



1) $v_i = v_{gs}$, $v_o = -g_m R_D v_{gs}$

$$\frac{v_o}{v_i} = -g_m R_D = A_v$$

2) $i_i = \frac{v_{gs}}{R_G}$, $i_o = -g_m v_{gs}$

$$A_i = \frac{i_o}{i_i} = -g_m R_G$$

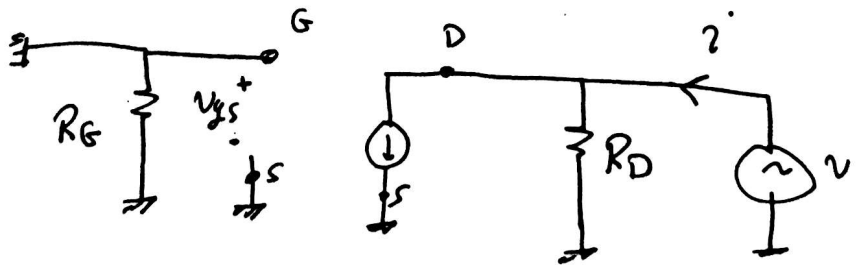
3) $R_i = \frac{v_i}{i_i} = R_G$

4) $R_o = ?$

i) Deactivate v_i

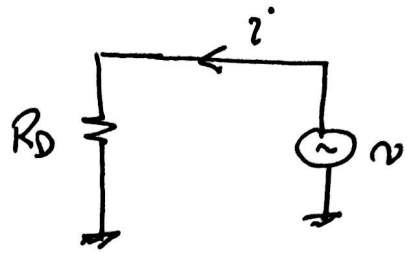
ii) Put  v at o/p

iii) $R_o = \frac{v}{i}$



v_{gs} = zero

$\because v_{gs} = zero \Rightarrow$

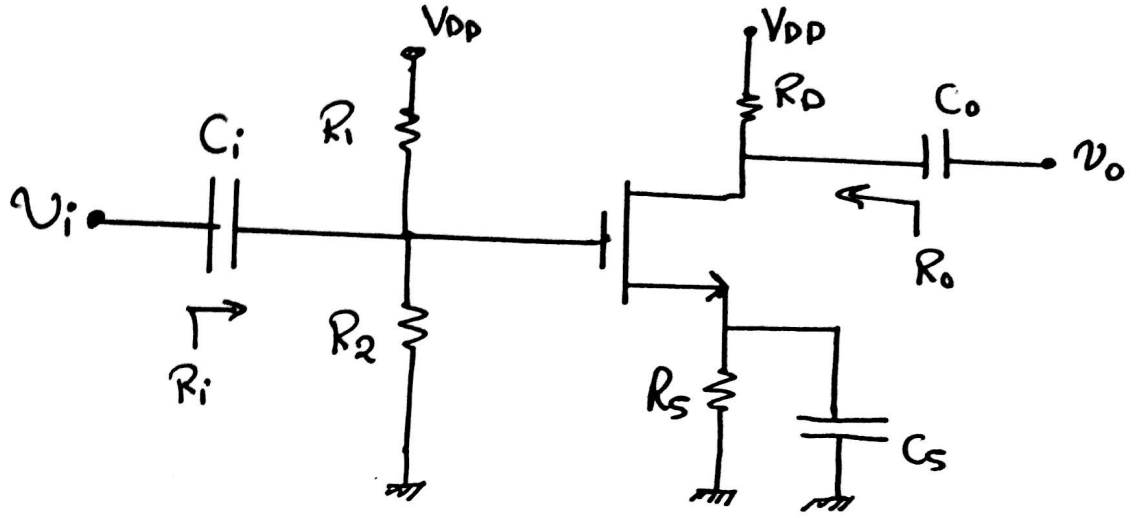


$$R_o = \frac{v}{i} = R_D$$

Summary of results:

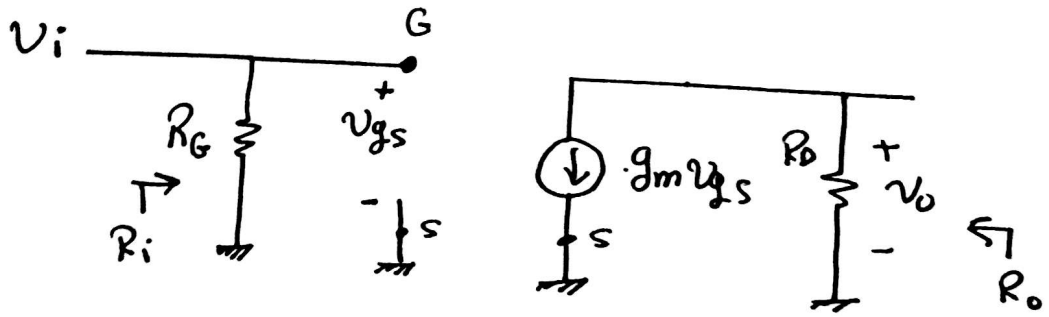
1. $A_v = -g_m R_D \longrightarrow |A_v| > 1$
2. $A_i = -g_m R_G \longrightarrow |A_i| > 1$
3. $R_i = R_G \longrightarrow$ High input impedance
4. $R_o = R_D \longrightarrow$ Moderate output impedance

* MOSFET Common source Amplifier:



Find A_v, A_i, R_i, R_o

Soln $R_G = R_1 // R_2$



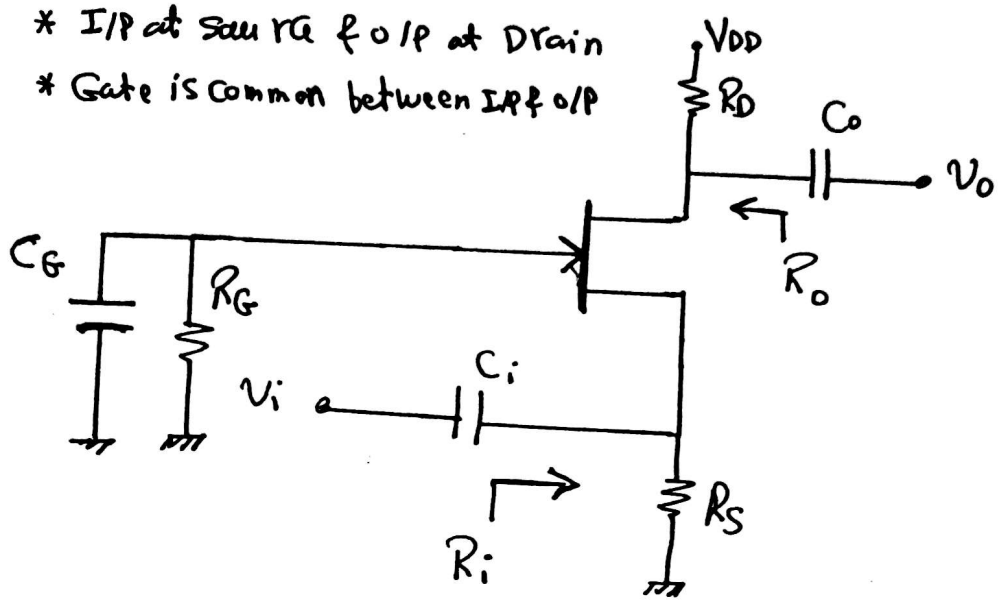
Note : Same as JFET, $g_m = K_n (V_{GS} - V_t)$

$A_v = -g_m R_D$, $A_i = -g_m R_G$

$R_i = R_G$, $R_o = R_D$

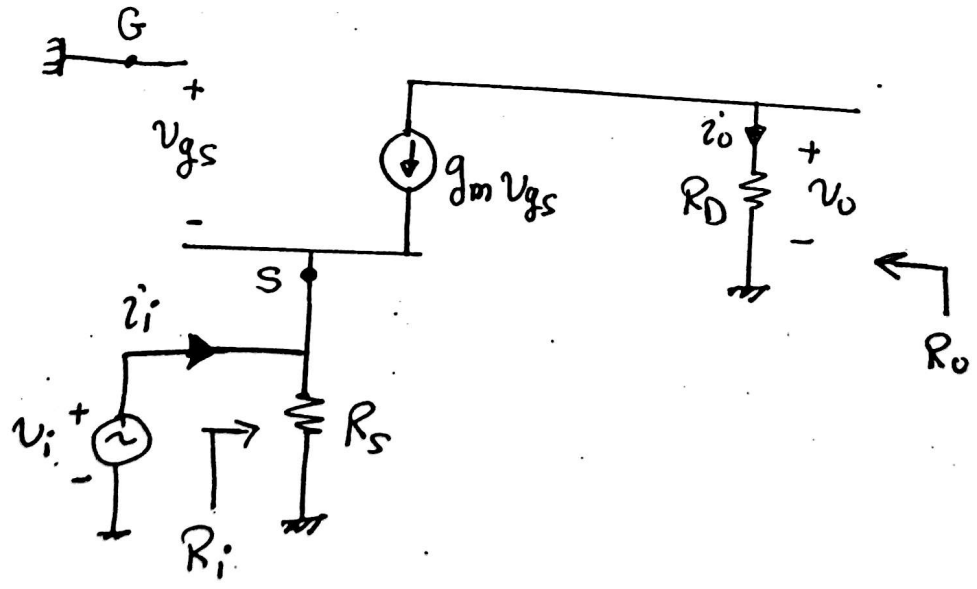
JFET Common gate Amplifier :

* I/P at source & o/p at Drain
* Gate is common between I/P & o/p



Find $A_v, A_i, R_i, R_o = ?$

Soln

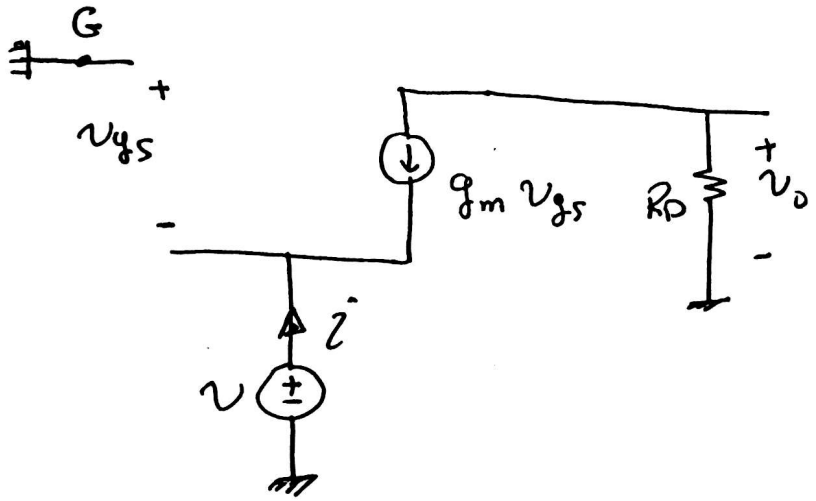


1) $v_i = -v_{gs}$, $v_o = -g_m R_D v_{gs}$

$A_v = \frac{v_o}{v_i} = +g_m R_D \Rightarrow$ gain has +ve Value.

2) $R_i = ??$

$R_i = R_S \,//\, R'$, $R' = ?$



$$R' = \frac{v}{i} = \frac{-v_{gs}}{-g_m v_{gs}} = \frac{1}{g_m} \Rightarrow R_i = R_S \,//\, \frac{1}{g_m}$$

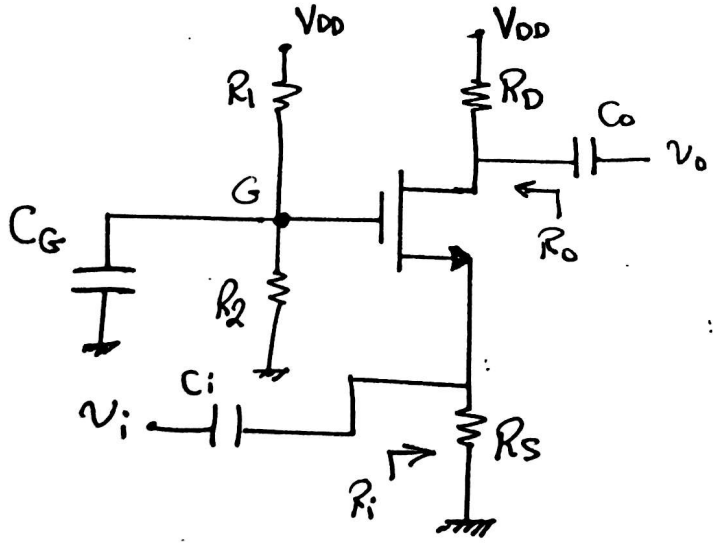
3) $R_o = R_D$

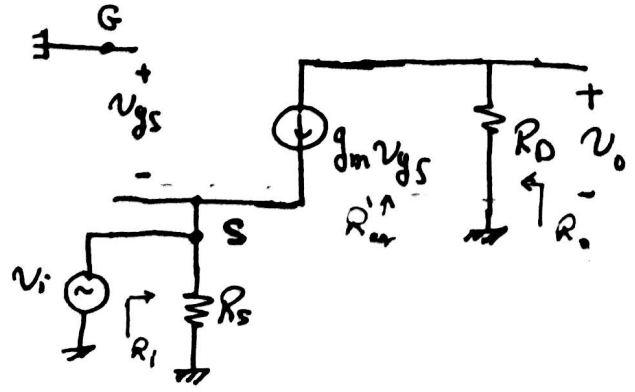
4) $$A_i = \frac{i_o}{i_i} = \frac{\frac{v_o}{R_D}}{\frac{v_i}{R_i}} = \frac{v_o}{v_i} * \frac{R_i}{R_D} = A_v \frac{R_i}{R_D} = g_m \left(R_S \,//\, \frac{1}{g_m}\right)$$

* Summary of JFET Common gate

* $A_v = g_m R_D$ (+ve Value) > 1
* $A_i = g_m (R_S // \frac{1}{g_m}) = \frac{g_m R_S}{1 + g_m R_S} < 1 \Rightarrow$ If $g_m R_S >> 1$ $\Downarrow$ $A_i \simeq 1$
* $R_i = R_S // \frac{1}{g_m}$ (Low)
* $R_o = R_D$ (moderate)

* MOSFET Common gate Amplifier:





* the same as JFET

$A_v = g_m R_D$

$A_i = \frac{g_m R_S}{1 + g_m R_S}$

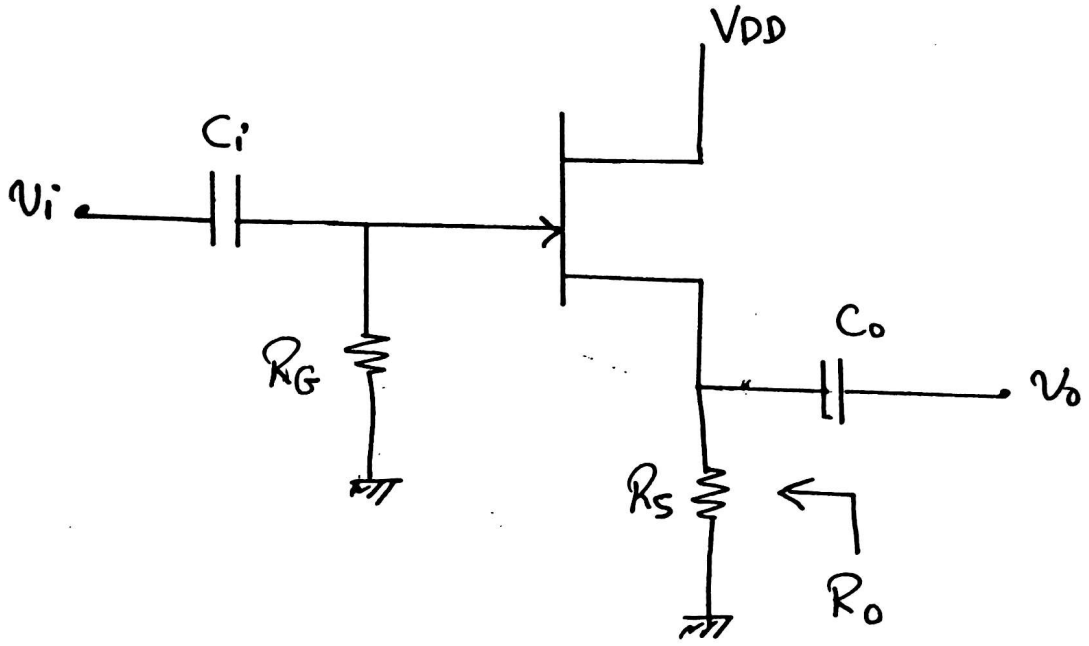
$R_i = R_S // \frac{1}{g_m}$

$R_o = R_D$

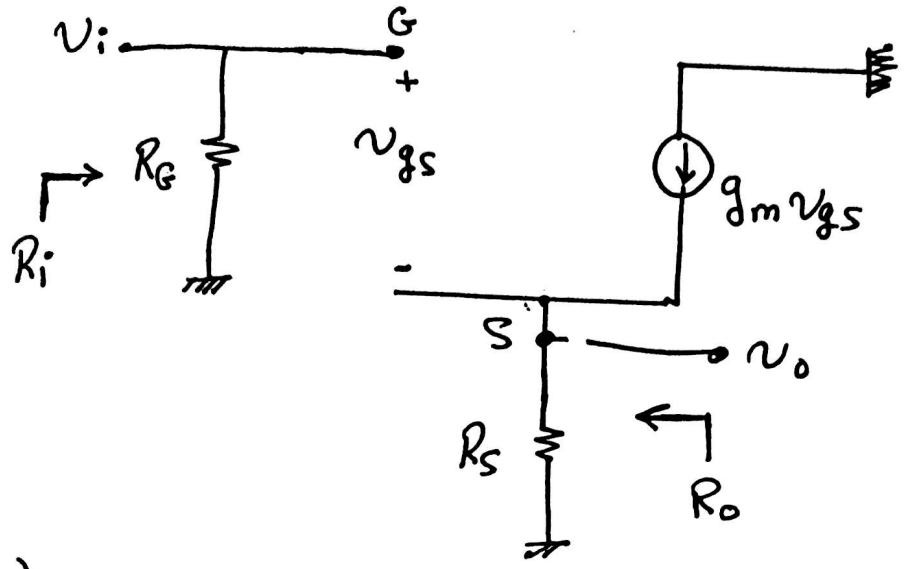
* Common Drain Amplifiers:

* Input at gate and output at source
* Drain is Common between i/p & o/p

JFET Common Drain Amplifier:



Find A_v, A_i, R_i and $R_o = ?$



1) $v_i = v_{gs} + g_m R_S v_{gs} = (1 + g_m R_S) v_{gs}$

$v_o = g_m R_S v_{gs}$

$$A_v = \frac{v_o}{v_i} = \frac{g_m R_S}{1 + g_m R_S} < 1$$

If $g_m R_S >> 1 \Rightarrow A_v \simeq 1$

* $R_i = R_G$, $R_o = R_S \,//\, \frac{1}{g_m}$
* $A_i = A_v * \frac{R_i}{R_S} = A_v * \frac{R_G}{R_S}$, $A_v \simeq 1$
* $A_i \simeq \frac{R_G}{R_S}$

* Summary of Common Drain JFET

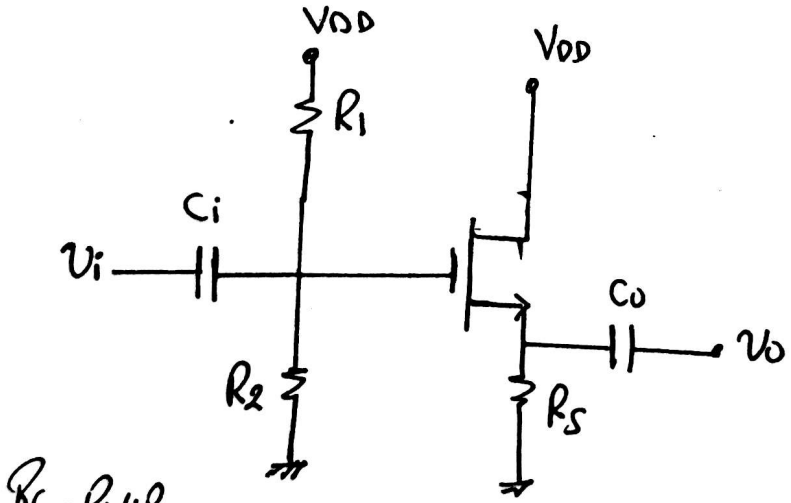
$$A_v = \frac{g_m R_s}{1 + g_m R_s} \simeq 1$$

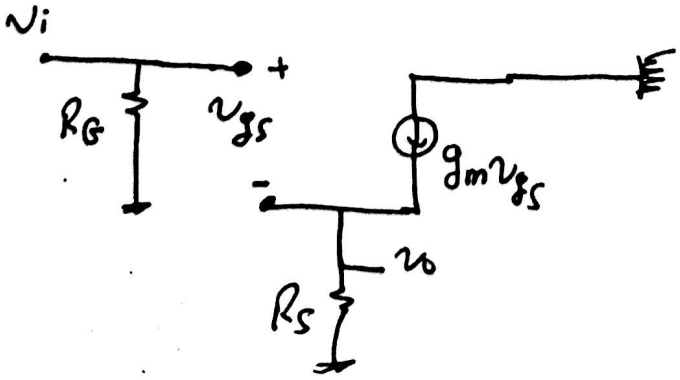
$R_i = R_G$ (high)

$R_o = R_s \,//\, \frac{1}{g_m}$ (Low)

$A_i \simeq \frac{R_G}{R_s}$ (High)

* MOSFET Common Drain Amplifier :





* the same as JFET

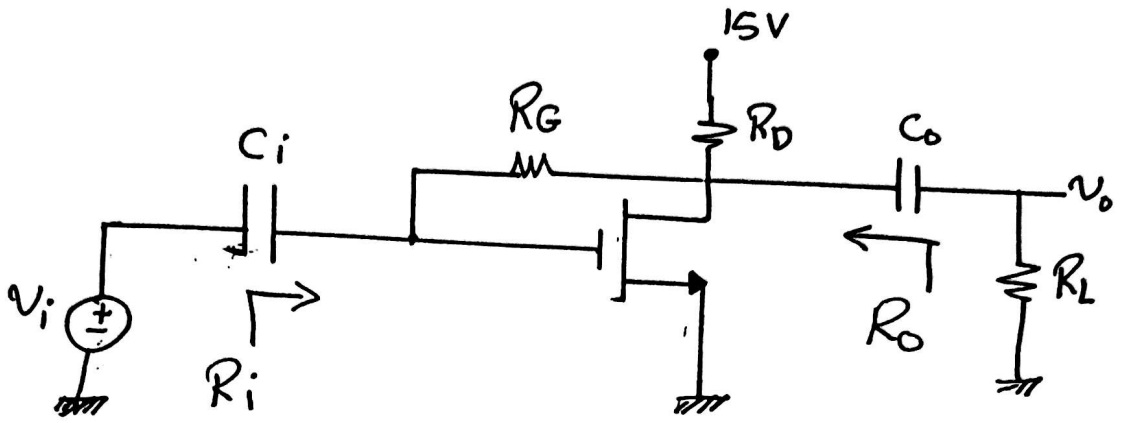
$A_v \simeq 1$

$A_i \simeq \frac{R_G}{R_s}$

$R_i = R_G$

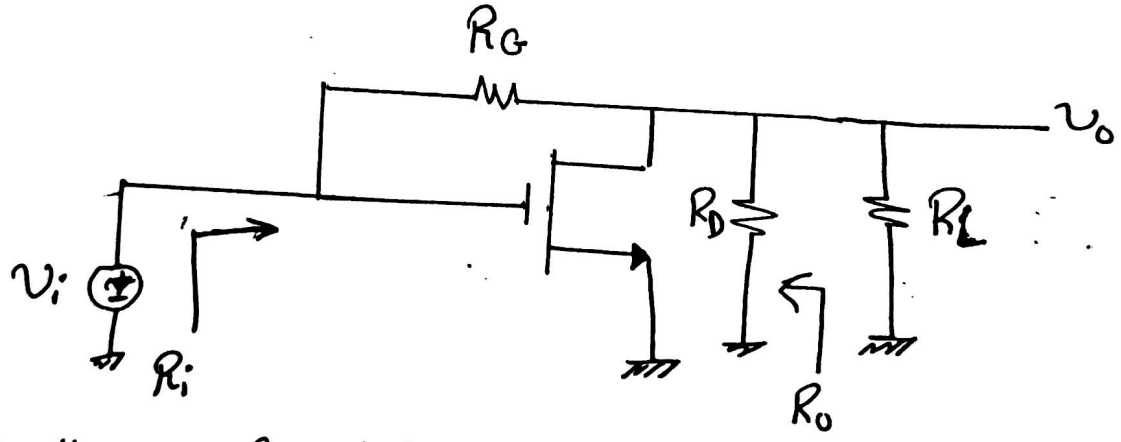
$R_o = R_s \,//\, \frac{1}{g_m}$

Pb:

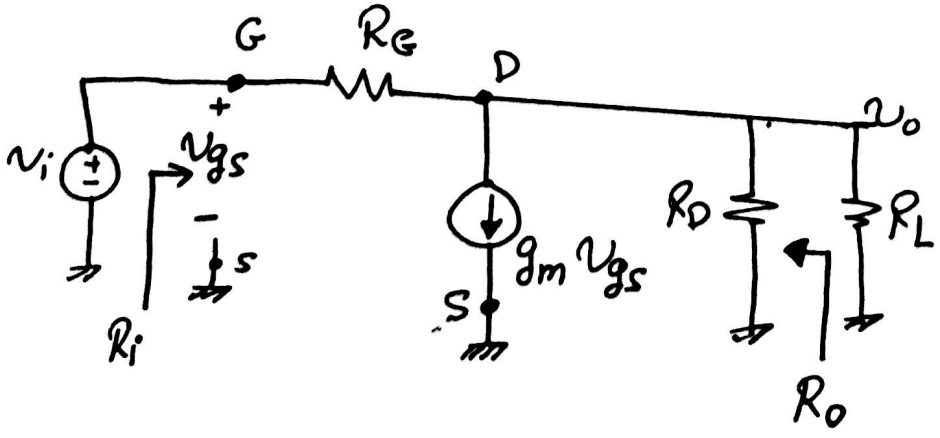


Find A_v, R_i, R_o

Ac circuit:



*small signal model:



Note $\longrightarrow$ $v_{gs} = v_i$

KCL at D : $\quad V_D = v_o$

$$\frac{v_o}{R_D // R_L} + g_m v_i + \frac{v_o - v_i}{R_G} = 0$$

$$v_o \left[\frac{1}{R_D // R_L} + \frac{1}{R_G}\right] = v_i \left[\frac{1}{R_G} - g_m\right]$$

$$A_v = \frac{v_o}{v_i} = \frac{\frac{1}{R_G} - g_m}{\frac{1}{R_G} + \frac{1}{R_D // R_L}}$$

note: If $R_G = 0 \longrightarrow A_v = -g_m R_D // R_L$

$$R_i = \frac{v_i}{i_i}, \quad i_i = g_m v_i + \frac{v_o}{R_D // R_L}$$

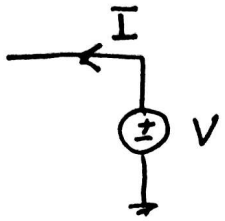
$$i_i = g_m v_i + \frac{1}{R_D // R_L} \cdot \frac{1/R_G - g_m}{1/R_G + 1/R_D // R_L} v_i$$

$$i_i = g_m v_i + \frac{1 - g_m R_G}{R_G + R_D // R_L} v_i = \frac{1 + g_m R_D // R_L}{R_G + R_D // R_L} v_i$$

$$R_i = \frac{v_i}{i_i} = \frac{R_G + R_D // R_L}{1 + g_m R_D // R_L} \quad *$$

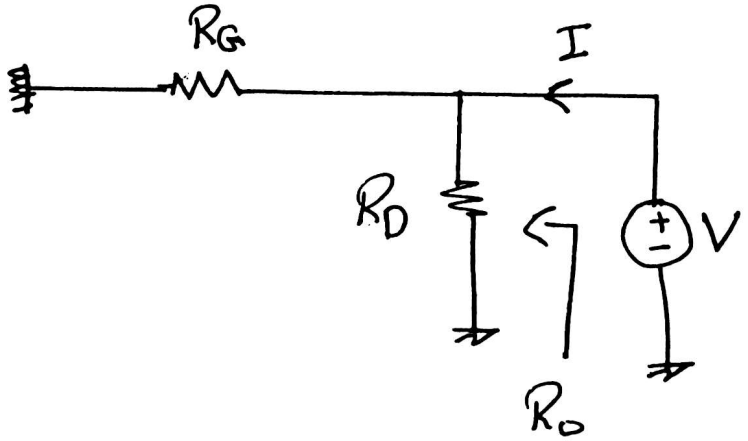
$R_o = ?$

1) $v_i = 0$

2) put  at o/p

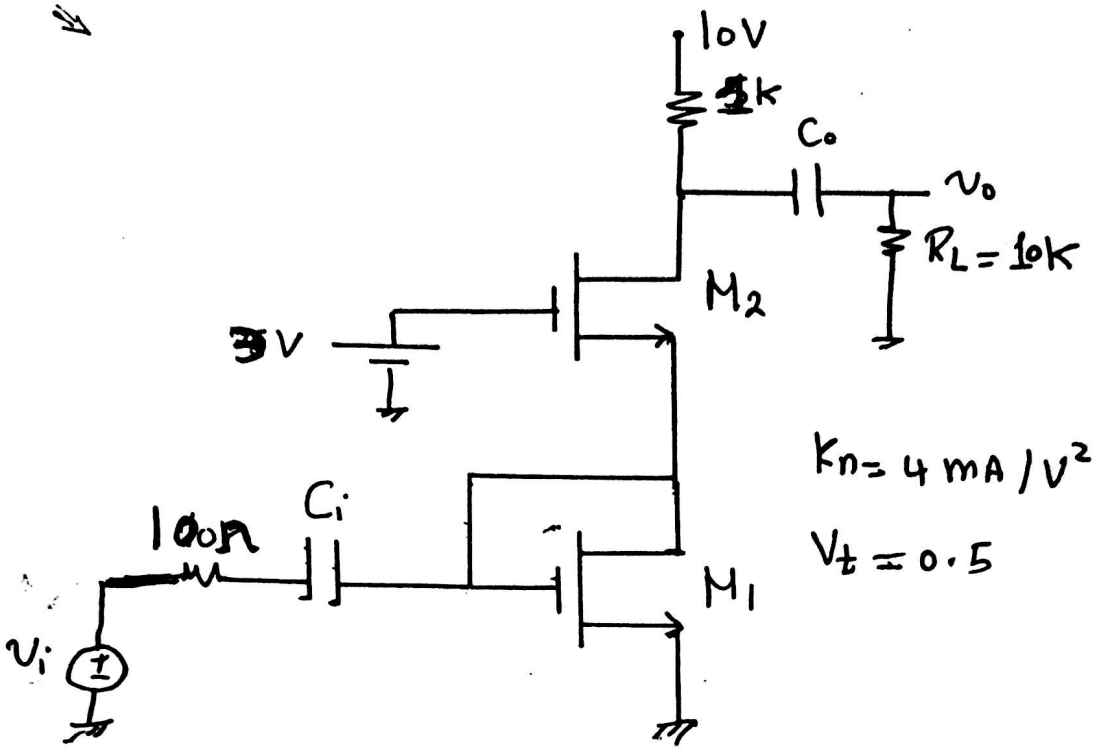
3) $R_o = \frac{V}{I}$

$\because v_i = 0 \longrightarrow v_{gs} = 0 \longrightarrow$ Current source is open circuit



$$R_o = \frac{V}{I} = R_G // R_D$$

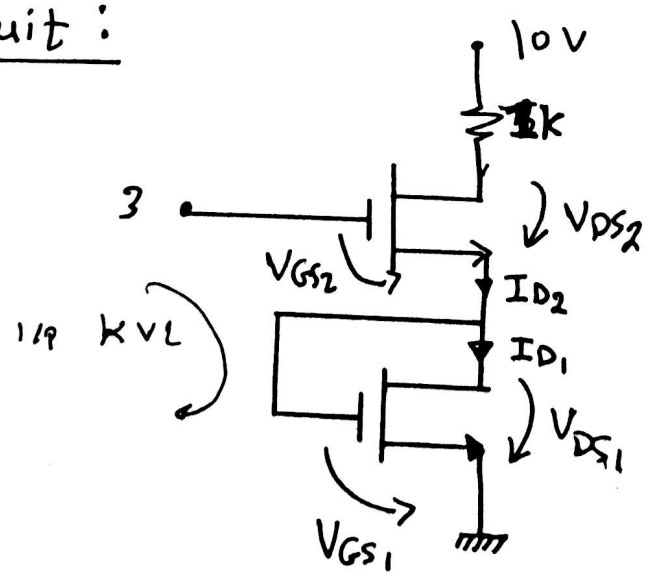
.Pb



Find $Av = \frac{v_o}{v_i}$

Soln at first, we want to find g_{m1} & g_{m2}

DC circuit:



* $I_{D1} = I_{D2}$, same K_n & V_t

 ⇒ $V_{GS1} = V_{GS2}$

$V_{GS1} + V_{GS2} = 3V \Rightarrow V_{GS1} = V_{GS2} = 1.5V$

For $M_1 \Rightarrow V_{DS1} = V_{GS1} = 1.5\ V$

$I_D = 2(1.5 - 0.5) = 2\ mA$

O/P KVL:

$-10 + 2 + V_{DS2} + 1.5 = 0 \longrightarrow V_{DS2} = 6.5\ V$

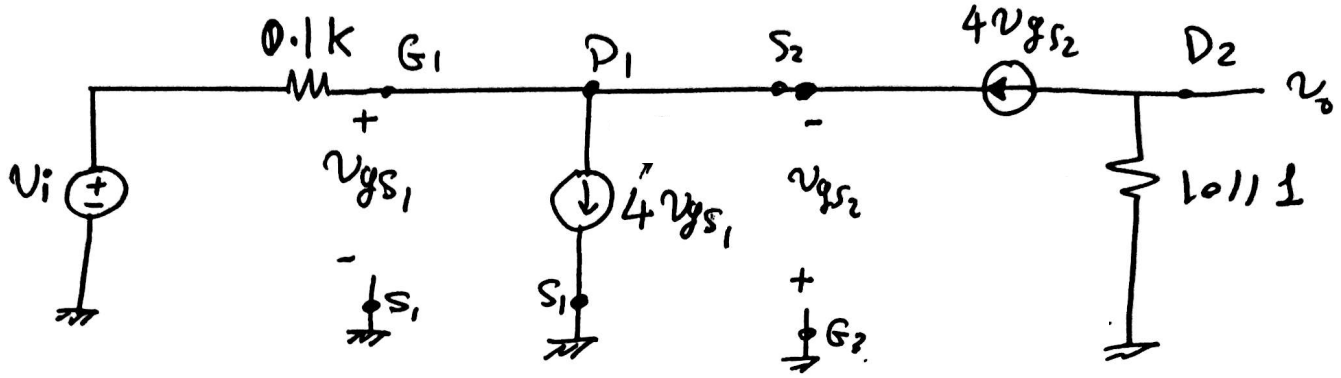
$V_{DS1} > V_{GS1} - V_t \longrightarrow M_1$ (Saturation)

$V_{DS2} > V_{GS2} - V_t \longrightarrow M_2$ (Saturation)

$g_{m1} = g_{m2} = K_n (V_{GS} - V_t) = 4(1.5 - 0.5)$

$g_{m1} = g_{m2} = 4\ mA/V$

Small Signal model:



$$v_o = -4 v_{gs2} (10//1) = -3.64\, v_{gs2} = 3.64\, v_{gs1}$$

KCL at D_1

$$4 v_{gs1} - 4 v_{gs2} + \frac{v_{gs1} - v_i}{0.1} = 0 \quad , \quad v_{gs1} = -v_{gs2}$$

$$v_i = 1.8\, v_{gs1}$$

$$A_v = \frac{v_o}{v_i} = \frac{3.64\, v_{gs1}}{1.8\, v_{gs1}} \cong 2$$